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Evaluation and Application of Enhancements to the Performance of the ASDE-3 Radar in Heavy Rain

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March 1982
Final Report

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16. Abstract

This report presents the results of a study performed by the Transportation Systems Center (TSC) to evaluate two proposed enhancements to the performance of the ASDE-3 Radar in heavy rain: Adaptive gain and adaptive clutter thresholding, (operating with frequency agility). The study was based on analysis of radar and rate of rainfall data collected by TSC during the ASDE-3 Engineering Tests and performance predicted by the ASDE-3 System Performance Model.

Both enhancements were found to be subject to errors due to non-uniformity of rain. Adaptive gain was found to be fail-soft and of net benefit to ASDE-3 performance whereas adaptive clutter threshold which is subject to error from variations in both clutter and attenuation was found not to be of benefit.

Information to aid in design and installation of an adaptive gain subsystem and alternative approaches for less demanding airports are also presented.

17. Key Words
ASDE; Airport Surface Detection Equipment; Radar Rain Performance; ASDE-3 Enhancements; Rain Attenuation; Rain Clutter

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PREFACE

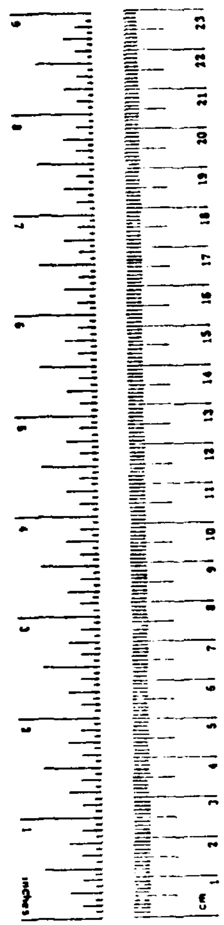
The Surveillance and Control Branch of the Transportation Systems Center, under the program management of the FAA Systems Research and Development Service ATC Automation Division has investigated two proposed enhancements to ASDE-3 (an advanced airport surface surveillance radar) which promised to improve the radar's performance in heavy rain. TSC had previously been responsible for the ASDE-3 development program which culminated in engineering and operational evaluation of an installed engineering model ASDE-3. Results from these tests indicated that rainfall performance could be improved further than the specified and demonstrated 16 mm/hour by the use of adaptive gain and threshold, operating with frequency agility.[1] After an initial evaluation of these proposed enhancements[2] it was decided that further field test data was required to resolve the primary performance issue relating to these enhancements: the impact of spatial variations in rainfall rate across the airport surface. A thorough alternatives analysis carried out for this investigation[3] revealed that the issue could be resolved through analysis of rainfall rate data available from the ASDE-3 Engineering Tests. The results of this effort are presented in this report.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

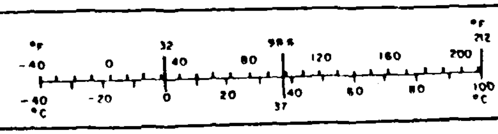
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF SYMBOLS AND ABBREVIATIONS

ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Control
DAS	Data Acquisition Subsystem
dB	Decibel power ratio of P_1 to P_2; $10 \log (P_1/P_2)$ voltage ratio of V_1 to V_2; $20 \log (V_1/V_2)$
DEU	Display Enhancement Unit
HP9825	Hewlet-Packard 9825 desktop controller-processor
FAA	Federal Aviation Administration
FAATC	Federal Aviation Administration Technical Center
m^2	Square meters (of radar cross-section)
mm/hr	Millimeters per hour
nm	Nautical mile
P_{fa}	Probability of false alarm
RR	Rainfall Rate
S/(N+C)	Signal to noise-plus-clutter ratio
STC	Sensitivity time control
TSC	Transportation Systems Center

EXECUTIVE SUMMARY

The results of this evaluation of the proposed adaptive gain and adaptive clutter threshold enhancements to the performance of the ASDE-3 radar confirm that adaptive gain will be of significant benefit to the ASDE in heavy rain or at far ranges. On the other hand, adaptive clutter thresholding, was found to have an unacceptably high percentage of "lost" targets since this proposed enhancement is subject to error due to variations of both rain clutter and attenuation, which are not correlated.

This evaluation also indicated that for the smaller, less demanding ASDE-3 configurations some simplified gain enhancements may be satisfactory. Analysis results are presented which will make it possible to determine whether this is true for the requirements of any individual ASDE-3 installation.

1. INTRODUCTION

The ASDE-3 Radar incorporates many novel features to enhance its performance in the surveillance of the airport surface for Air Traffic Control (ATC). Engineering tests of the ASDE-3 Radar indicated that two additional features, adaptive gain and adaptive clutter thresholding, could greatly enhance performance of the ASDE-3 in rain, particularly in heavy rain or at the farther ranges. The function of adaptive gain would be to counteract attenuation of the radar signal as it passes through the rain. This would be accomplished by applying additional gain to the radar signal according to a pattern, varying with range and azimuth, that is determined by sampling field reflector returns in real time. The function of an adaptive clutter threshold would be to remove from the radar signal the clutter that is caused by part of the radar signal being reflected back from the raindrops themselves. This would be accomplished in a similar fashion as adaptive gain with the samples being taken from low ambient reflectivity airfield areas.[2]

This report presents an evaluation of the performance and merits of these enhancements based on empirical data from the ASDE-3 Engineering Tests, and gives recommendations of what rain performance enhancement should be incorporated in the production ASDE-3 Radar.

2. PERFORMANCE EVALUATION OF ADAPTIVE GAIN AND CLUTTER THRESHOLD

Studies were made of several approaches to the task of evaluating the performance of the adaptive gain and adaptive clutter threshold enhancements for the ASDE-3 radar. It was determined that an analysis based on ASDE-3 Engineering Test rainfall rate data could be used to obtain an evaluation of the performance of adaptive gain and clutter thresholding. The evaluations are presented in Section 2.1 to 2.4 below. Details of the studies of the other evaluation approaches are given in Appendix B.

2.1 EVALUATION OF ADAPTIVE GAIN PERFORMANCE VIA ANALYSIS OF ENGINEERING TEST DATA

An adaptive gain and thresholding subsystem would typically measure attenuation and clutter levels at points about 9,000 feet from the radar, and 60 degrees apart in azimuth. The subsystem would predict conditions between the measurement points by employing an interpolation scheme. If attenuation and rain clutter levels were known from test measurements at two such points and also at a point midway between them at the same range, then off-line interpolation could be performed, based on the measured values at the extreme points, and checked by comparison with the measured value at the midpoint.

While this simultaneous radar data was not taken during the ASDE-3 test program, rainfall rate data was recorded simultaneously on three test pads. These test pads were set on a radial at ranges of 500 feet, 4846 feet and 8600 feet from the radar site. Thus the spacing of pads 1 and 3 was 8100 feet, which is approximately the spacing of measurement points for

adaptive gain and clutter threshold, and pad 2 was about midway between pads 1 and 3.

If we were to assume that the radar location had been moved so that these pads were all approximately 8100 feet from the radar, and assume that the rainfall rate is constant from each pad to the radar, (constant in the radial direction only), we would have an excellent model of one section of the adaptive gain and clutter threshold measurement configuration. This is diagrammed in Figure 2.1-1.

To analyze the performance of adaptive gain, attenuation to each pad from the new radar location was calculated based on this assumption that the rainfall rate is constant from the pad to the radar. (This made the attenuation values dependent on the rainfall rates measured at the pads and may show more variation than was actually present since a large part of the attenuation would be due to rainfall at near ranges where there is more correlation between the three paths than at the pads.) At pad 2 attenuation was calculated both from the measured rainfall rate and by interpolation between the attenuations calculated from the rainfall rates measured at pads 1 and 3.

Table 2.1-1 shows the process used to accumulate statistics on adaptive gain performance using attenuation calculated from simultaneous rainfall rate measurements, and the assumptions described above.

Table 2.1-2 presents the statistical results grouped into different rainfall rate categories and grouped according to whether adaptive gain wouldd have provided too much gain (+), too little gain (-), as well as the absolute error in gain for all situations. From Table 2.1-2 we can see that for rainfall rates between 70 and 20 mm/hr, adaptive gain would provide too much gain at the mid (worst case) point 80% of the time, and the mean error there would be about 6 dB. Too little gain would be

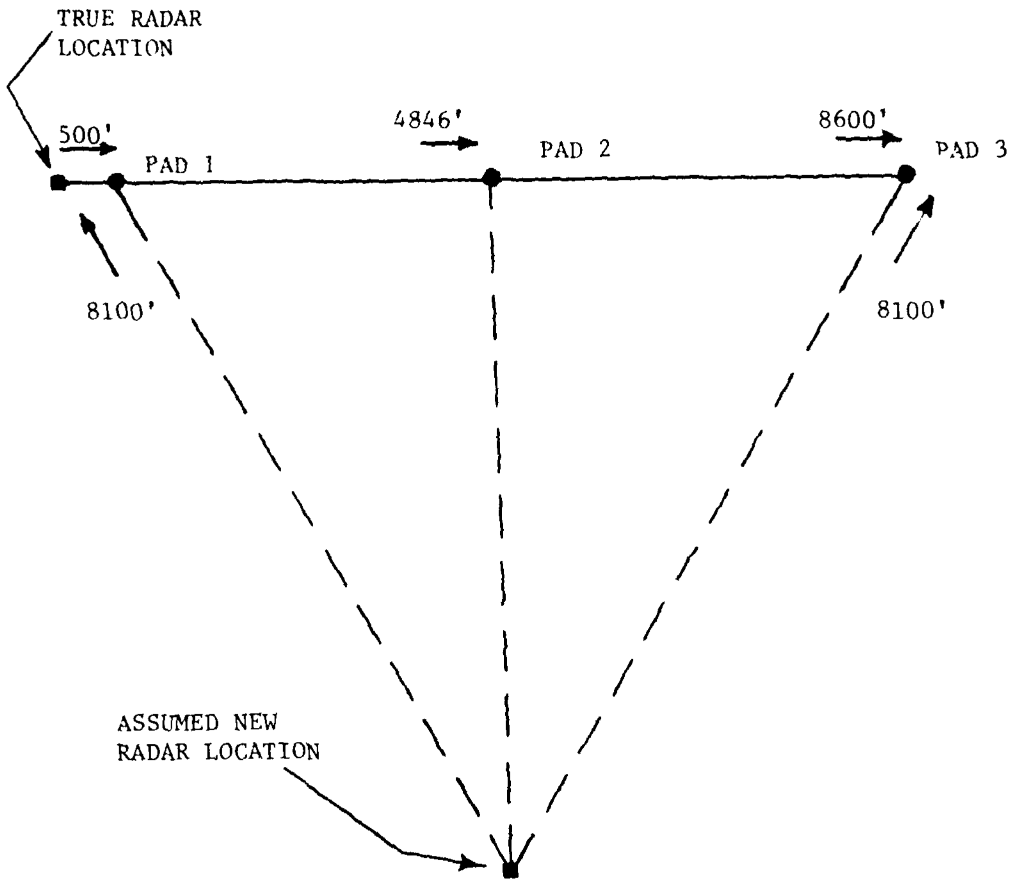


FIGURE 2.1-1. ASDE-3 TEST PAD CONFIGURATION, APPLIED TO CALCULATION OF ATTENUATION VARIANCE

provided 20% of the time at the worst case point, and the mean error would also be about 6 dB. For both situations the standard deviation of the error is about 4 dB.

When the adaptive gain function applies too little gain, this would still represent an improvement over the situation where there is no adaptive gain function since some gain has been applied to counteract the attenuation.

When the adaptive gain function applies too much gain no harm is done to target detectability until the target begins to saturate on the display. As adaptive gain causes the target to saturate then the target to clutter ratio is reduced. As the gain increases past this point the target-to-clutter ratio decreases until the rain clutter also saturates, at which point the target becomes totally undetectable. This situation would not occur except at very high rainfall rates, for example where the target-to-clutter ratio for a 3 m^2 target falls below 6 dB (which occurs for rainfall rates above 80 mm/hr at 9000 feet and for rainfall rates above 32 mm/hr at 18,000 feet (see Figure 4.2-1). A reduction in signal to clutter ratio is only significant if the target is visible on the display to begin with. Typically, for cases where adaptive gain may cause a reduction in signal to clutter ratio, attenuation would have been so great that $3m^2$ or smaller targets would not have been visible without adaptive gain. The exact performance is a function of range, rainfall rate and display configuration. An analysis of system performance and an example for a particular display configuration are given in Section 4.2.

Even in the infrequent cases where the targets become lost due to adaptive gain's causing saturation of rain clutter on the display, the operator would be <u>aware</u> that there is a problem in that region because it would "white-out". Without adaptive gain

TABLE 2.1-1. PROCESS FOR ACCUMULATING STATISTICS ON VARIATION BETWEEN MEASURED ATTENUATION AT 8100 FEET AND ATTENUATION DERIVED FROM INTERPOLATION BETWEEN ADJACENT ATTENUATION MEASUREMENTS

1) Read and calibrate the Rainfall Rate observed @ each pad this second.

2) Calculate attenuation that would be observed for a target on each pad based on the assumption that the rainfall rate observed at that pad was uniform between that pad and the radar site, and the assumption that all 3 pads are 8100' from the Radar site.

3) Interpolate linearly between the attenuation values calculated in (2) for pads 1 and 3, based on the actual physical distances between the pads, to obtain an attenuation value for pad 2.

4) Calculate the difference, in dB, between the two values of attenuation for pad 2.

5) Accumulate statistics for the difference in attenuation by:
   1. whether the interpolated value is + or - relative to the observed value, and absolute value of the difference.
   2. for all rain data
   3. for rain data where at least one pad showed RR>20mm/hr
   4. for rain data where at least one pad showed RR>20mm/hr but <70mm/hr

TABLE 2.1-2 ERROR IN PREDICTED ATTENUATION MIDWAY BETWEEN TWO PADS AT 8100 FEET RANGE

	Error in Predicted Attenuation					
	Mean	Std. Dev.	Max	Min	Qty. Samples	
All Rainfall Rates Observed	4.8dB	7.3dB	34.6dB	0.0dB	1060	abs*
	5.3	7.6	34.6	0.0	711	+
	3.7	6.3	30.1	0.0	349	-
Rainfall Rates >20mm/hr	9.1	8.2	34.6	0.0	528	abs
	9.1	8.4	34.6	0.0	402	+
	9.3	7.6	30.1	0.1	126	-
Rainfall Rates >20mm/hr & <70mm/hr	5.8	4.0	19.1	0.0	354	abs
	5.7	3.8	19.1	0.0	284	+
	6.1	4.6	16.5	0.1	70	-

*abs: absolute difference between attenuation predicted from the calculated attenuation at the other two pads and the attenuation calculated from the rainfall rate measurement at this pad.

\+ : statistics on those measurements where the predicted attenuation (as above) exceeded the calculated attenuation (as above)

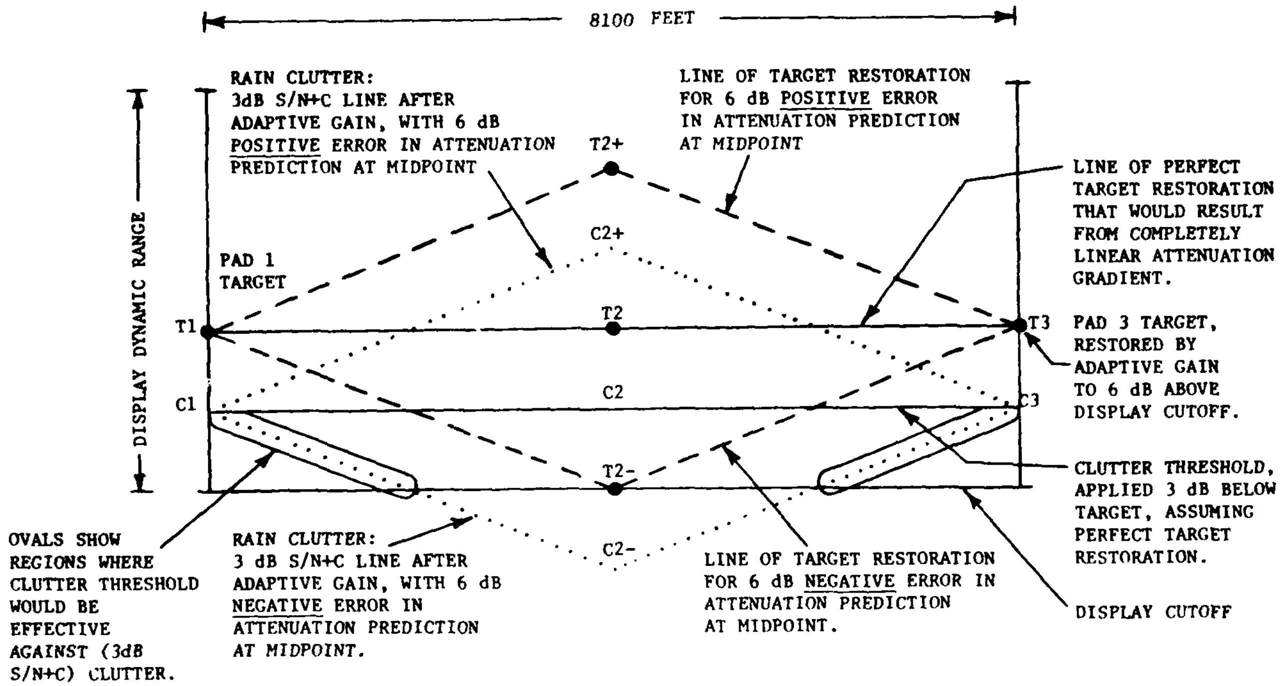
\- : statistics on those measurements where the predicted attenuation was less than the calculated attenuation.

the attenuation at these higher rainfall rates would be heavy enough to push some desired targets below display threshold and the operator could be unaware that he has lost these targets. This is especially likely if the operator is using the Display Enhancement Unit to remove returns from the background areas. (These background returns would normally fade as attenuation becomes severe and thus warn the operator that he could be losing targets). Thus the adaptive gain function would generally restore lost targets even at these heavy rainfall rates, and adaptive gain would be 'fail-soft' - since it would be easy to recognize situations where targets might be lost in rain clutter.

2.2 EVALUATION OF ADAPTIVE CLUTTER THRESHOLD PERFORMANCE

The adaptive gain evaluation statistics of Table 2.1-2 can also be used to derive several conclusions regarding the performance of an adaptive clutter threshold. To arrive at these conclusions we first assume that the rain clutter is uniform across the region where the measurement points are located (which would be the optimum condition for removing it with a threshold). If this mean clutter level falls below the -6 dB point relative to the smallest desired target there is little to be gained in thresholding to remove clutter since S/N+C > 6 dB. On the other hand, if the mean clutter level falls above the -6 dB point relative to the smallest desired target, a threshold could remove most of the clutter (since we assumed it was uniform) but according to the results of Table 2.1-2 we would be removing mean target returns over some part of the region. This situation is illustrated in Figure 2.2-1 where the uniform mean clutter is assumed to be 3 dB below the target level and the threshold is applied at that level. Based on the statistics of Table 2.1-2 this threshold would remove clutter at most 20% of the time the rainfall rate was between 20 and 70 mm/hr,(only 10% if the target is 6 dB above display cutoff as shown), yet another 10% of the time the threshold would be removing the mean target return.

From the above discussion we can see that under the best assumption on clutter behavior, where we could expect to do the best job of removing clutter with a threshold, we would begin to remove desired targets nearly as often as we removed clutter, due to the variation in attenuation over the region where we are applying the enhancements via interpolation. It follows that things do not improve when we take account of the real situation where clutter is not uniform. In fact, a rain clutter threshold would have even greater errors at the point midway between clutter measurements than the adaptive gain function would. This is because the adaptive gain is applied to counteract a large



ASSUMPTIONS: SMALLEST DESIRED TARGET IS 6 dB ABOVE DISPLAY CUTOFF IN CLEAR WEATHER.
S/N+C IS CONSTANT AT 3 dB - UNIFORM CLUTTER, OPTIMUM FOR THRESHOLDING.

Figure 2.2-1. EXAMPLE OF IMPACT OF ADAPTIVE GAIN AND CLUTTER THRESHOLD DERIVED FROM RAINFALL RATE DATA MEASURED AT THE TARGET LOCATIONS

scale phenomenon, (attenuation due to all the rain in the line between the target and the radar), whereas rain clutter is a local phenomenon caused by the rain that is within a few tens of feet of the target location, and has a much higher variance.

2.3 POSSIBLE MECHANISM FOR ERRORS IN ADAPTIVE GAIN BEING WEIGHTED TOWARD EXCESS GAIN

Within storms having heavy rain there exist localized cells that cause high attenuation. Some indication of this was observed in the initial analysis of ASDE-3 test data (see Appendix A, p. A-25.) Low attenuation is caused by a distributed region of low rainfall rate, thus there can be no localized cells that cause low attenuation readings.

If a localized rain cell causes a high attenuation reading at one measurement point the result will be adaptive gain applying excess gain to the large regions on all sides of that measurement point. Whereas, if a localized rain cell causes high attenuation at a point between measurement points, the result will be adaptive gain applying insufficient gain only at the point of high attenuation and in a narrow azimuth region radially beyond it.

A target will experience excess gain whenever a region of high attenuation affects either of the two measurement points adjacent to the target. On the other hand, a target will experience insufficient gain only when a region of high attenuation affects it directly. This suggests that excess gain would occur twice as often as insufficient gain since one region of high attenuation could cause excess gain on the same target two ways but could only cause insufficient gain one way.

Actually, excess gain should occur more than twice as often as insufficient gain since all target in the regions surrounding a measurement point will experience excess gain every time that point is affected by a region of high attenuation, but when a region of high attenuation causes a target to experience insufficient gain usually only one target is affected.

Thus adaptive gain, using linear interpolation, should apply excess gain more than twice as often as it applies insufficient gain. This corresponds with the results of the evaluation presented in Section 2.1.

2.4 SUMMARY OF EVALUATION RESULTS

Evaluation of the adaptive gain enhancement for ASDE-3 indicates that it would be beneficial to ASDE-3 performance in heavy rain. Adaptive gain would enhance the ASDE-3's performance by restoring targets to normal brightness levels on the display when the targets have been attenuated by heavy rain.

Because the adaptive gain function would measure attenuation at widely separated points on the airfield and interpolate between these measurements, the variance of rainfall across the field would introduce errors to the gain correction. In general, these errors introduced to adaptive gain's target restoration process by the spatial variance of rainfall would not be serious.

This evaluation indicates that adaptive gain would be 'fail-soft' because the majority of errors would apply <u>excess</u> gain which would not normally cause loss of target detection. Under the most severe conditions, when rain clutter brightness approached the brightness of small targets, excess gain could cause a localized white-out on the display, resulting in a loss of target detection in that region. This would be a 'fail-soft' situation because a localized white-out would be a <u>visible</u> failure, whereas, without adaptive gain the same severe conditions would probably result in localized attenuation of both target and clutter to a level below display cutoff, which would be an <u>invisible</u> failure. On the other hand, the smaller percentage of cases where adaptive gain would provide <u>insufficient</u> gain to offset attenuation, the net result would still be an improvement in target detection because some additional gain would be provided to the attenuated region.

Evaluation of the adaptive clutter threshold enhancement for the ASDE-3 indicates that although it could be effective in a local region around a point where clutter is measured, on the large scale the variations in clutter level would render its effectiveness minimal and, worse, variations in attenuation would result in a clutter threshold removing targets a large percentage of the time. In short, a clutter threshold has a low probability of being effective against rain clutter and a high probability of removing desired targets almost as much as it would remove rain clutter.

3. CONSIDERATIONS IN DESIGN OF AN ADAPTIVE GAIN SUBSYSTEM

3.1 *REFLECTOR SITING FOR ADAPTIVE GAIN*

The siting of calibrated reflectors on the airport surface, for use in measuring attenuation caused by rain, is limited by practical constraints and airport geometry. To reduce installation costs the quantity of reflectors should be minimized, yet for optimum adaptive gain performance the number of reflectors should be as large as the adaptive gain processing can handle. In addition there must be some flexibility in the processing and margin in the number of reflectors that allows for the fact that airport geometry will not permit every reflector to be optimally located.

The evaluation presented in Section 2.3 indicates that a 60° spacing between reflectors would be adequate for airports of 9,000 feet or smaller radius. For 360° coverage this would require six reflectors. Full coverage of 18,000 feet range and 360° would require eighteen reflectors, if the spacing were approximately consistent with the 9,000 foot case. Figure 3.1-1 shows the arrangement of these reflectors, using equidistant spacing of the relectors. Although it provides good spatial coverage, this arrangement would probably not be used since interpolation calculation would be simplified if the far targets were all at approximately the same range. The reflector arrangement shown in Figure 3.1-2 includes this improvement, and, in addition, no two reflectors are co-radial, giving better accommodation for azimuthal variation in attenuation, and allowing reflector sampling by a single gating device.

The interpolation processing should be able to accommodate variations in reflector siting and a proportional reduction in target range for airports with maximum radius between 9,000 and 18,000 feet.

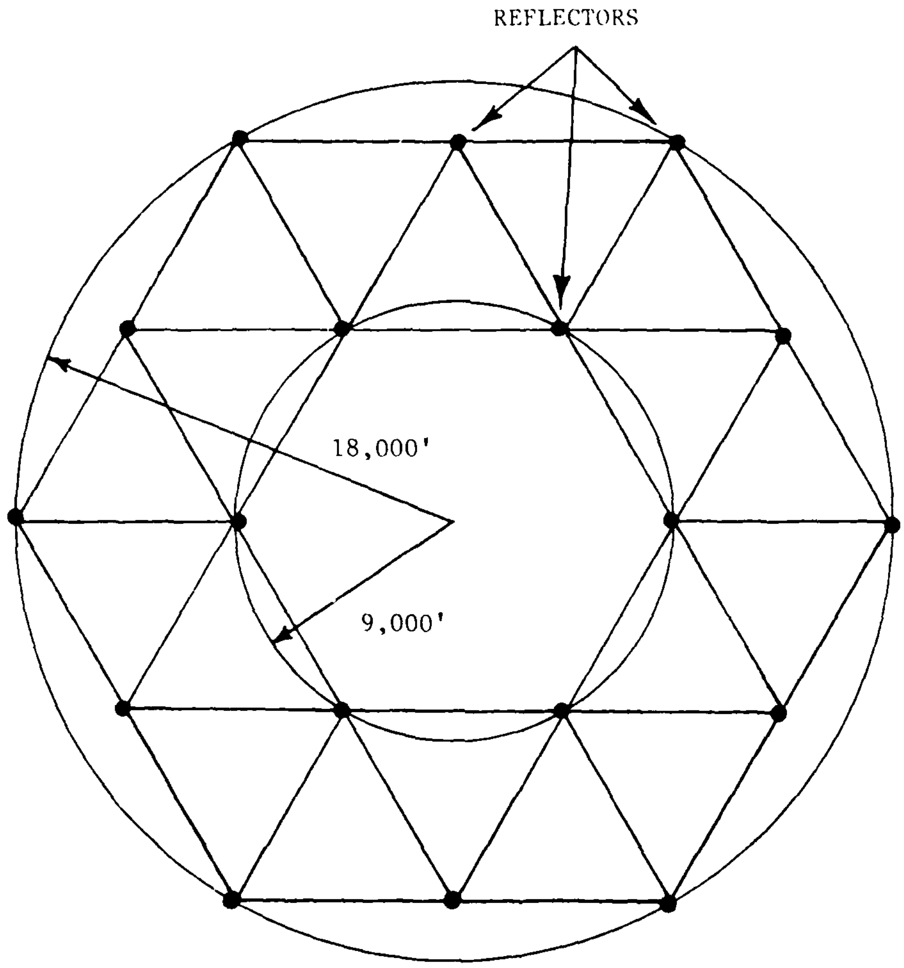


FIGURE 3.1-1. MAP OF REFLECTORS FOR MEASURING ATTENUATION - EQUIDISTANT SPACING

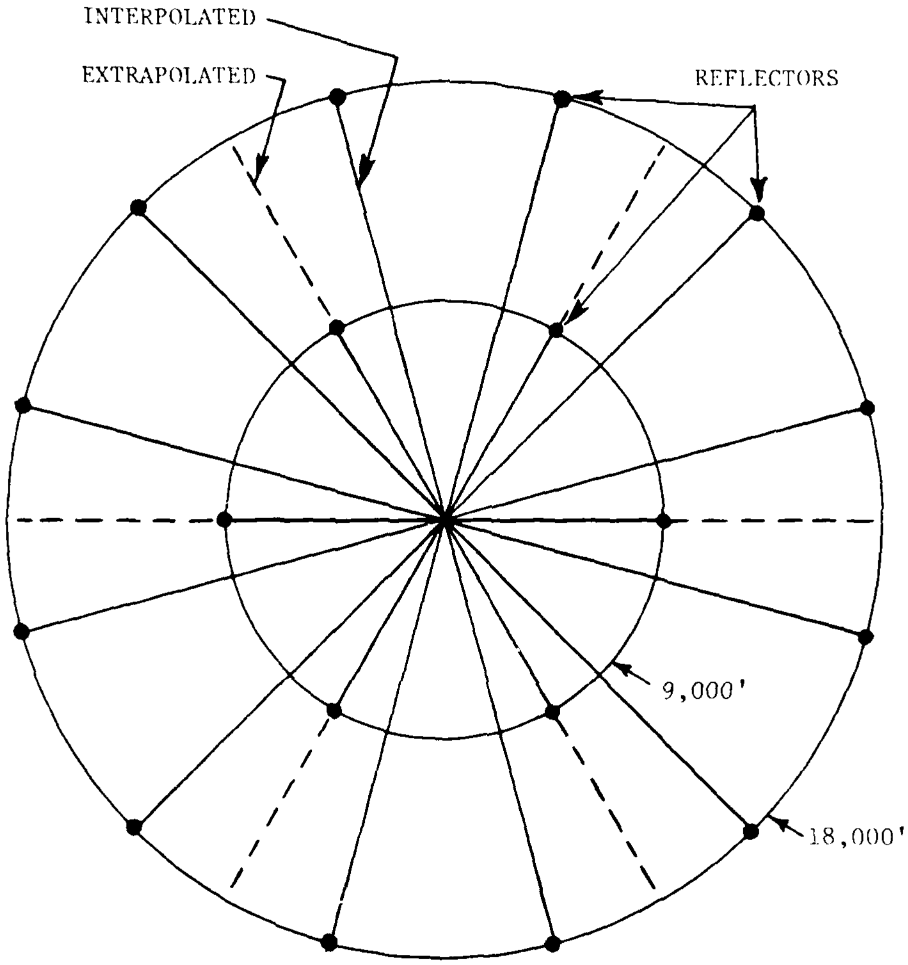


FIGURE 3.1-2. MAP OF REFLECTORS FOR MEASURING ATTENUATION - REFLECTORS SPACED SO NO TWO ARE CO-RADIAL

3.2 REFLECTOR SIZE AND CONFIGURATION FOR ADAPTIVE GAIN

Several general requirements affect the configuration of the calibrated reflectors that must be located on the airport surface for attenuation measurement in the adaptive gain function. The size of the reflectors must be small enough that the receiver is not saturated by the return signal. They should also be installed in a region of low grass return so the grass returns, which are changeable, will not seriously affect the measurement of the reflector returns. Since the reflector's return includes a ground path return, the reflectors have to be carefully positioned in height above ground so that the return is at a maximum. If the reflectors' returns were not "peaked" in this fashion, small changes in reflector position would cause large changes in the return. Runway/taxiway lights would not be suitable for use in attenuation measurement because they are not adjustable to compensate for ground reflections, and they are very likely to be obscured by ground traffic.

To enable measurement of the greatest range of attenuation, reflector size must be chosen so the return, when peaked for ground-bounce-lobing, is one dB or more below the receiver's one dB compression point. (This should be done at midband, in clear weather). The reflector should be as bright as possible consistent with the above requirement. However, an additional range of attenuation could be accommodated by placing larger reflectors, which are large enough to saturate the receiver in clear weather, adjacent to each small reflector. As attenuation increases, the larger reflector's return would drop below receiver saturation and could be used to measure larger amounts of attenuation.

3.3 SEPARATE RECEIVE CHANNEL FOR ADAPTIVE GAIN

If the clear weather returns from a reflector used to measure attenuation are near the 1 dB compression level of the receiver (which is desirable to maximize the range of attenuation that can be measured) and the attenuation measurement is made from the radar signal downstream of the point where adaptive gain is applied, there will be a feedback problem. This problem can be seen by considering the situation where significant attenuation exists, but the displayed reflector return has been restored to its level near saturation by adaptive gain. If on the next scan the attenuation should fall sharply, the displayed reflector return would be saturated. The measurement of the reflector return would only show part of the decrease in attenuation, and this part is all that could be adjusted for by reducing gain before the next scan. Several scans could pass by before the system 'caught up'.

If a separate receive channel is established so that the reflector measurements are made upstream of the adaptive gain function but downstream of STC there will be no adaptive gain feedback and the measured return from a reflector will remain at or below its clear weather level. The use of this separate receive channel would require the sampling device to have additional resolution to accurately measure the attenuated reflector returns.

3.4 ADAPTIVE GAIN CURVES

The gain curves could be pre-calculated and stored in read-only-memories to speed the adaptive gain processing. Since attenuation never decreases with increasing range the quantity of curves required can be manageable. For example, in the case of an adaptive gain curve from 0 to 18,000 feet range the zero range point has no attenuation and if the 9000 foot point were allowed

8 levels of attenuation and the 18,000 foot point were allowed 16 levels of attenuation only 136 curves of 36 points each would need to be stored. This is derived from the fact that there would be only eight allowable curves between zero and 9,000 feet, and from each allowed attenuation level at 9,000 feet a curve can only be drawn to an equal or higher level at 18,000 feet.

In implementing adaptive gain, the interpolation function should take into account the tendency for adaptive gain to apply excess gain for more often than too little gain, as described in Sections 2.2 and 2.3. For example, if the attenuation shows a significant change between two measurement points the gain-vs-azimuth curve applied to correct for the attenuation could be one that is non-linear and decays quickly from the higher value.

4. CONSIDERATIONS IN INSTALLATION OF AN ADAPTIVE GAIN SUBSYSTEM

The addition of an adaptive gain function to the ASDE-3 system will improve the performance of ASDE-3 for all ranges and tower heights by compensating for attenuation due to rain. For example, without adaptive gain all non-saturated target returns would disappear from the display before the rainfall rate reached 16 mm/hr at the maximum range of 18,000 feet.

At any particular range the amount of adaptive gain required to restore target returns to clear weather brightness levels is a function of the rainfall rate at which operation is required. However, the amount of adaptive gain available at a given range (which determines the maximum rainfall rate for which targets can be restored to clear weather brightness) is a function of the total gain capability of the receiver and the antenna gain at the given range - which is determined by the antenna elevation pattern and tower height.

At shorter ranges more adaptive gain is available to compensate for attenuation, but attenuation is also less for a given rainfall rate. Thus if adaptive gain is applied at these ranges it extends operation to very heavy rainfall rates. In some short range configurations a fixed addition to the STC curve could acceptably be used in place of adaptive gain. Details on these points and analyses that will support configuration choices that must be made for individual ASDE-3 sites are given in the sections that follow.

4.1 IMPACT OF TOWER HEIGHT ON BENEFITS OF ADAPTIVE GAIN

Because receiver gain is limited to 60 dB in the ASDE-3 specification and because the amount of receiver gain available for adaptive gain is reduced by the amount of gain applied to STC at each range, there will be a decreasing amount of adaptive gain available with increasing range. It follows that there is a maximum rainfall rate (which decreases with increasing range) beyond which the adaptive gain function can no longer correct attenuation. The available adaptive gain at each range is also a function of tower height because a change in tower height produces a change in the elevation angle of each point on the field, and the antenna elevation pattern is not uniform.

Figure 4.1-1 shows plots of the maximum rainfall rate at each range for which adaptive gain could correct attenuation with the specified receiver gain and antenna elevation pattern. Curves are presented for three tower heights. The curves of Figure 4.1-1 do not include any correction for the fact that attenuation measured with the ASDE-3 Engineering Model radar exceeded predictions, (see Section 4.2). The curves for the 40 foot and the 100 foot towers show that the specified receiver gain is more than sufficient to restore clear weather target brightness (using adaptive gain) in 16 mm/hr rain at 18,000 feet range with a 100 foot tower, but marginal with a 40 foot tower.

4.2 IMPACT OF RANGE AND RAINFALL RATE ON BENEFITS OF ADAPTIVE GAIN

Figure 4.2-1 shows the calculated performance of the 'specified system' ASDE-3 for varying range and rainfall rate. These curves were derived using the ASDE-3 Radar System Detection Performance Model.[4]

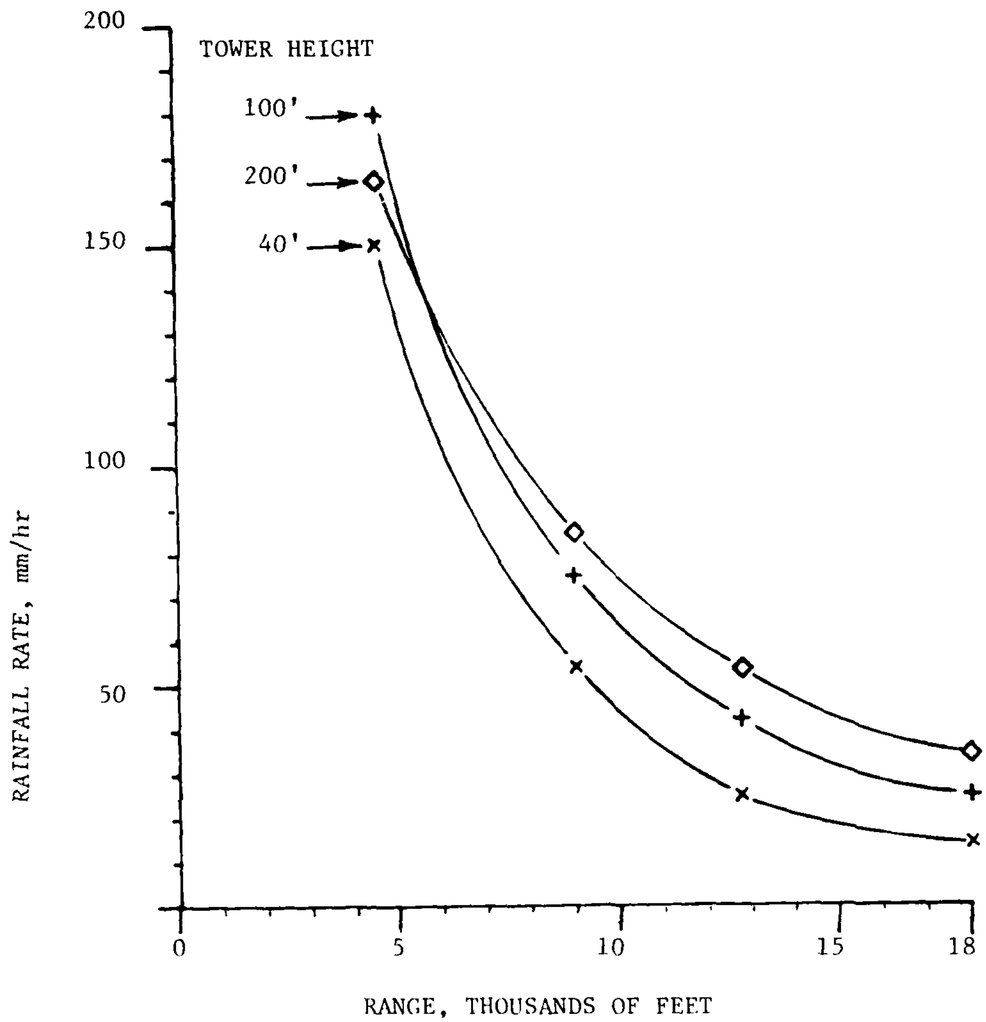


FIGURE 4.1-1. HIGHEST RAINFALL RATE FOR WHICH ASDE-3 ADAPTIVE GAIN COULD COMPENSATE FOR ATTENUATION AT EACH RANGE

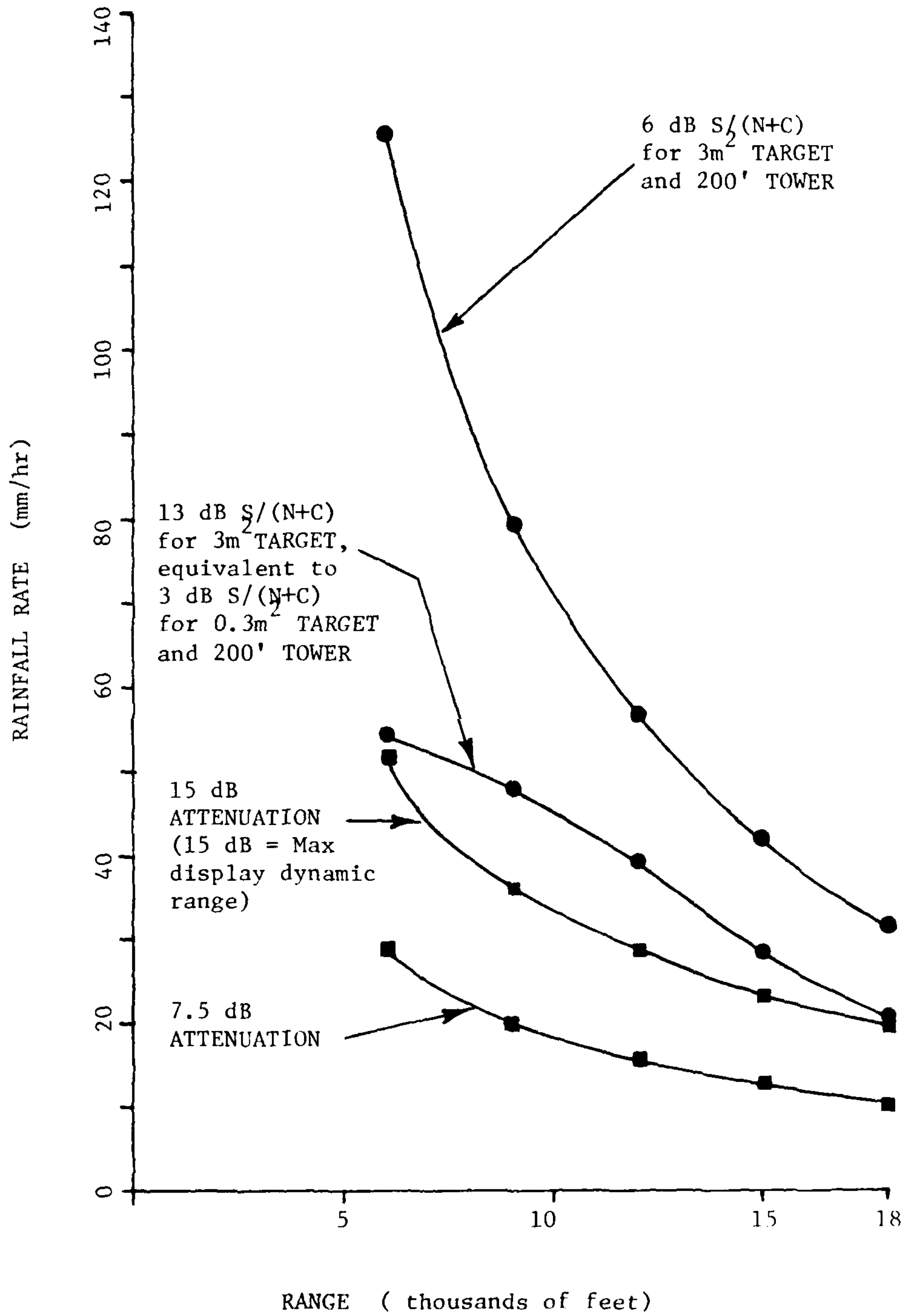


FIGURE 4.2-1. PERFORMANCE OF "SPECIFIED SYSTEM" ASDE-3

For any given range the "15 dB attenuation" curve may be thought of as giving the rainfall rate at which the returns from all targets that are not saturated in clear weather will have been attenuated from the display, if adaptive gain is not in use. Likewise, the "7.5 dB attenuation" curve gives the rainfall rate at which any target return that would have been below the midpoint of the display dynamic range in clear weather will be attenuated below the display threshold, if adaptive gain is not employed.

The fact that the "13 dB S/N+C" curve lies consistently above the "15 dB attenuation" curve means that at any particular range, when the rainfall rate has become just great enough to attenuate all non-saturated targets from the display, the rain clutter level will still be at least 13 dB below the return from a 3m^2 target. So, if the display system were configured so that the return from a 3m^2 target were 13 dB above display threshold in clear weather, adaptive gain could be used to correct at least 15 dB of rain attenuation at any range beyond 6,000 feet, without making rain clutter visible on the display.

In the above example, if adaptive gain were to err by applying 6 dB too much gain, (as would be the case 80% of the time with a linear gain correction - see Section 2.1), the mean 3m^2 target return would be driven 4 dB into saturation and the mean clutter return would be 6 dB above display cutoff. This means that <u>with</u> adaptive gain we would restore totally lost 3m^2 and smaller targets, and reduce out S/N+C to 11 dB from 13 dB. So for this display configuration we pay a penalty of 2 dB in a <u>meaningless</u> S/N+C in order to restore our 3m^2 and smaller targets by 15 dB.

From Figure 4.2-1 we can also see that to compensate for attenuation at a range of 18,000 feet in 16 to 20 mm/hr of rain either adaptive gain must be used on 15 dB of extra gain must be applied across the board. If we take into account the fact that the attenuation curves in Figure 4.2-1 are derived from the standard formula[5] whereas observations made during the ASDE-3 engineering tests (see Figure 4.2-2) found attenuation to be 3 to 4 dB higher than the formula predicted, the 15 dB of extra gain described above should be raised to 18 dB.

For the ASDE-3 Engineering tests the display system was configured with $3m^2$ targets saturated by about 8 dB. So, in clear weather 18 dB of extra gain would have put $3m^2$ targets 26 dB into saturation on the display with accompanying resolution loss.

With the 18 dB of attenuation we could expect at 18,000 feet with 16 to 20 mm/hr rain and without extra gain, a $3m^2$ target would have been attenuated to a point 5 dB above display cutoff, a $1m^2$ target would be at display cutoff and a $0.4m^2$ target would be 5 dB below cutoff. (These figures are based on TSC's measurement of a $0.4m^2$ target at 12.9 dB above, display cutoff in clear weather during the ASDE-3 engineering tests, see Table 4.3.2). However, the ASDE-3 engineering tests showed that desired small targets can appear smaller than $0.3m^2$, and under the rain conditions described above we would expect these targets to be more than 5 dB below display cutoff if extra gain were not applied.

At 9000 feet range Figure 4.2-1 predicts that the 15 dB of attenuation due to rain would not be experienced until the rainfall rate was on the order of 37 mm/hr. The same figure shows that the rain clutter level can be about 3 dB below a $0.3m^2$ target at these rainfall rates. When this is coupled with the fact that a $0.3m^2$ target would be about 3 dB below display

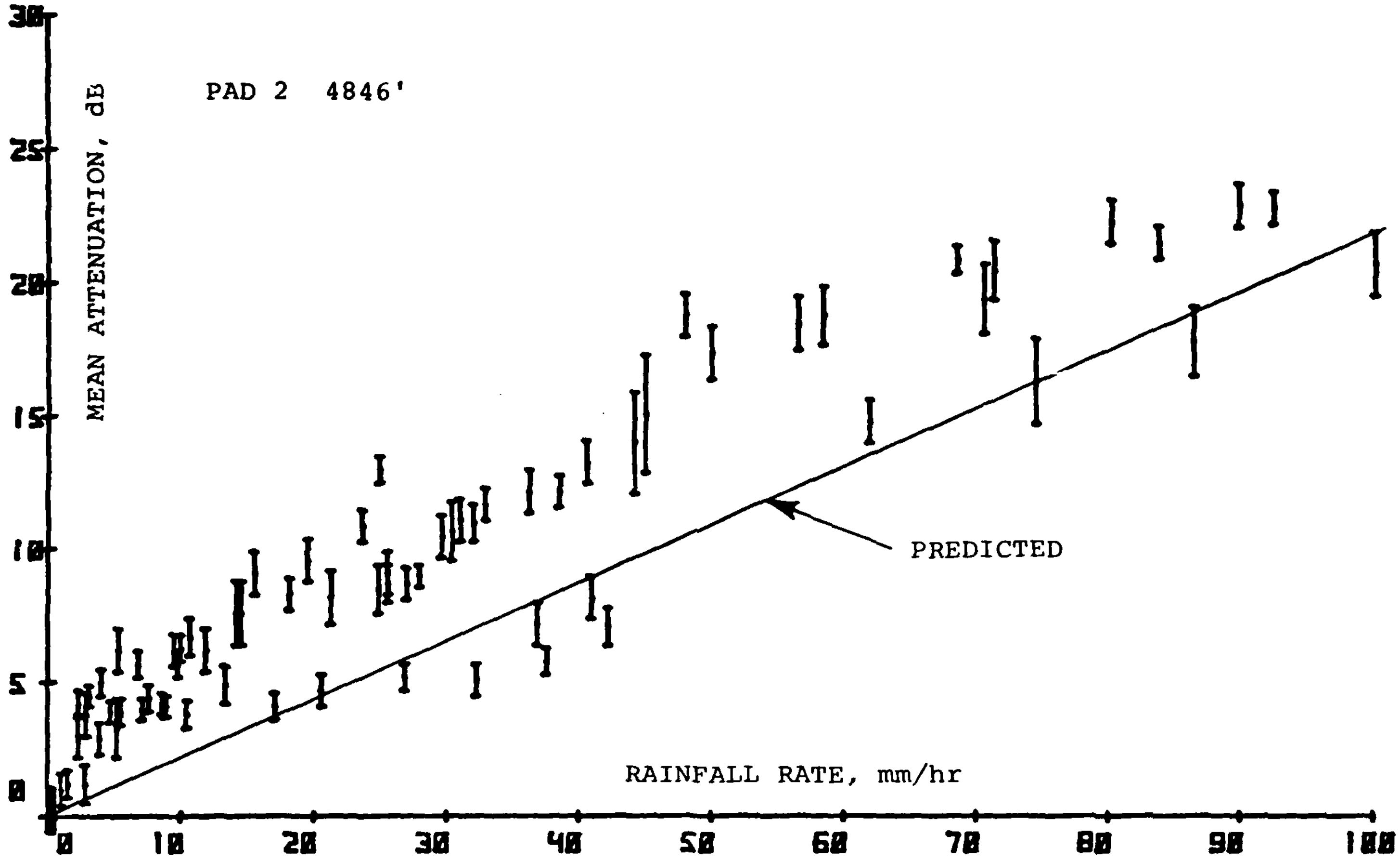


FIGURE 4.2-2. MEASURED ASDE-3 ATTENUATION VS RAINFALL RATE

saturation in clear weather (see Table 4.3.2 - TSC configuration), it is clear that the adaptive gain function's applying too much gain by 6 dB or more would cause a localized white-out on the display. This reinforces the recommendation of Section 3.4 to use a non-linear gain curve for adaptive gain to minimize saturating the rain clutter returns.

The above analysis suggests that for the less busy airports with maximum ranges of 9000 feet or less where it is not desired to compensate for attenuation in very heavy rain, the adaptive gain function could be acceptably supplanted by permanent (not adaptive) alteration in the STC function. The altered STC curve would provide 7 to 8 dB of extra (beyond what is required for STC) gain at 9,000 feet and no extra gain at ranges of 2,000 feet or less, where clutter dominates. In clear weather this extra gain would saturate many small targets that would otherwise not be saturated, cause a general reduction resolution on the display and cause targets to become somewhat brighter with increasing range. However, observations and analyses presented in Section 4.3 indicate that this loss of resolution would not be unacceptable. Further, the altered STC curve could be incorporated into the system as an operator-selectable function rather than replacing the unaltered clear weather STC curve. This would minimize resolution loss and variations in target brightness with range.

4.3 OBSERVED PERFORMANCE OF ASDE-3 AT SHORTER RANGES IN HEAVY RAIN

During the ASDE-3 engineering tests, performed by TSC, measurements were taken of target attenuation and rain clutter returns at test pad 2, which is located 4846 feet from the radar site. Table 4-3-1 gives some of these results at three heavy rain rates, expressed relative to the ASDE-3 display threshold. The returns that would be visible on the display are noted with an asterisk. For this TSC configuration of the radar only reflectors $3m^2$ or larger would remain detectable on the display at the range for rain rates above 70 mm/hr. Also, the rainfall rate would have to be less than 50 mm/hr for a $3m^2$ target to be above the middle of the display dynamic range.

Subsequent to the ASDE-3 engineering tests performed by TSC, FAATC re-configured the ASDE-3 for operational tests. The re-configuration included changing the RF amplifier, installing an STC curve and removing 5 dB of attenuation from the IF amplifier. The net result of these changes at the range of test pad 2 was an increase in gain of 4 dB over that which obtained during the TSC measurements.

Observations and video tapes made by FAATC with the re-configured ASDE-3 show little display degradation out to a range of about 1 nm for rainfall rates in the vicinity of 70 mm/hr.

The same configuration was used by FAATC for the entire operational test period, which included several observations in rainstorms, although the rainfall rates were not recorded. In general, target detectability in rain was considered acceptable.

Table 4.3-2 presents calculated target returns levels vs display threshold in both clear weather and heavy rain for both the TSC and FAATC configurations of the ASDE-3. The calculations are based on clear weather target return levels measured during the ASDE-3 engineering tests. The attenuation formula was used to determine the target return levels in heavy rain. This value was then adjusted downward according to actual ASDE-3 engineering test measurement results which were more conservative, (see Table 4.3.1 and Section 3.4).

The calculated target return levels for heavy rain given in Table 4.3-2 show that with conservative calculations (allowing for measured attenuation being greater than predicted - see Section 4.2) a $3m^2$ or larger target should be observable at 5,000 feet range in up to 80 mm/hr of rain on an ASDE-3 system with 4 dB of extra gain applied 'across the board'. Thus, the observations on an ASDE-3 system with 4 dB of extra gain are confirmed by calculation based on ASDE-3 engineering model test data. This tends to substantiate performance predictions calculated from the system performance model (see Section 4.2), that for some ASDE configurations at small airports extra gain applied "across the board" as an adjustment to the STC curve could be used to supplant the adaptive gain function.

TABLE 4.3-1. OBSERVED TARGET & CLUTTER RETURNS VS RAIN RATE RELATIVE TO DISPLAY THRESHOLD VS RAINFALL RATE

Rain Rate at Pad 2	Ø.4m² Target (measured return from T2 on Pad 2)	1.Øm² Target (derived from Ø.4m²)	3.Øm² Target (derived from Ø.4m²)	Peak of Frequency Agile Clutter (measured)	Clutter Peak after "Rain" Gain (for Ø.4m² Target)
48 mm/hr	-2.6dB	+2.4dB*	7.4dB*	-5.ØdB	+1Ø.5dB*
73 mm/hr	-8.2	-3.2	+1.8dB*	-9.8dB	+11.3dB*
91 mm/hr	-13.2	-8.2	-3.2dB	-14.ØdB	+12.1dB*

(dB level is relative to display threshold)

Location: Pad 2, 4846 feet range

(Each point is average of 24 Sec. of data)

(Ø.4m²) Target level in clear weather: +12.9 dB

* = Visible on display

TABLE 4.3-2. CALCULATED TARGET RETURN LEVELS, RELATIVE TO DISPLAY CUTOFF, IN CLEAR WEATHER AND HEAVY RAIN

	Calculated Clear Weather Target Return Level, Relative to Display Cutoff, db		Calculated Target Return Levels In Heavy Rain, Relative to Display Cutoff, db (FAATC Configuration Only)			
Target Size, M^2	TSC System Config.	FAATC System Config.	Attenuation Formula 70 mm/hr	Attenuation Formula 80 mm/hr	Attenuation Formula & Adjustment for Measured Atten. 70 mm/hr	Attenuation Formula & Adjustment for Measured Atten. 80 mm/hr
0.4	+12.9*	+16.9	+0.1	-2.7	-3.2	-6.1
1.0	+17.9	+21.9	+2.3	+2.3	+1.7	-1.1
3.0	+22.9	+26.9	+10.1	+7.3	+6.7	+3.9

*ASDE-3 Engineering Test Measurement

5. CONCLUSIONS

Adaptive gain will be beneficial to the performance of ASDE-3 in heavy rain. Adaptive gain enhances the ASDE-3's performance by restoring targets to their normal brightness levels on the display after they have been attenuated by heavy rain. Although errors can be introduced by the spatial variance of rainfall, evaluation shows that on average these errors are not large enough to negate the benefits of adaptive gain which has 'fail-soft' performance.

Performance of adaptive gain can be optimized by proper selection of the number and location of field reflectors, measuring reflectors' attenuation with video from upstream of the point where adaptive gain is applied (to avoid feedback), and by tailoring the gain curves to adjust for the tendency of linear gain correction to overestimate the gain needed.

As an alternative to implementing adaptive gain at the smaller, less busy airports, the STC curve could be adjusted on a non-adaptive basis to provide some extra gain. This would improve ASDE-3 performance in moderate rainfall but would cause more target returns to be saturated on the display in clear weather, resulting in a degradation of system resolution that would worsen with increasing range. This approach would have no flexibility to compensate for greater or non-uniform rainfall. However, it could be satisfactory for the smaller airports with lower traffic loads. If operationally acceptable, this adjusted STC function could be made a manually selectable operating mode for the system.

Evaluation of the adaptive clutter threshold function indicates that it would not be beneficial to the performance of ASDE-3 in heavy rain. Although a clutter threshold can be effective in a local region around a measurement point, it has a low probability of being effective against rain clutter in regions between measurement points - due to the high variance of rain clutter over the airfield. Furthermore, due to the variance of attenuation over the airfield, which is independent of clutter variation, a clutter threshold would have a high probability of removing desired targets almost as much as it removes rain clutter.

6. RECOMMENDATIONS

An adaptive gain function, to compensate for attenuation due to rain, should be included in the specification for the ASDE-3 radar.

An adaptive clutter threshold function, should not be included in the specification for the ASDE-3 radar.

An examination should be made of the requirements at the less demanding of the proposed ASDE-3 sites to determine if adaptive gain or an adjusted STC function should be installed.

7. REFERENCES

1. Bloom, P.J., G.J. Bishop, and J.E. Kuhn, "Detection Performance Evaluation of the ASDE-3 Using Fixed Frequency and Frequency Agile Operation," FAA-RD-81-41 (March 1981)

2. Appendix A, this report

3. Appendix B, this report

4. Bloom, P.J., et al, op. cit., Section 5.6.

5. Air Force Cambridge Research Labs, "Handbook of Geophysics and Space Environments", P 9-15.

APPENDIX A: ADAPTIVE GAIN AND CLUTTER THRESHOLDING: ENHANCEMENTS TO THE PERFORMANCE OF THE ASDE-3 RADAR IN HEAVY RAIN

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LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT.)

INTRODUCTION

This report describes the observed effects of rain on the ASDE-3 airport surface radar performance and provides an initial evaluation of the impact of two new design features, adaptive gain and adaptive clutter threshold, on the target detection performance of the radar in heavy rain.

In addition, a new way of implementing the adaptive clutter threshold is described, which make it more feasible than previously believed. The adaptive gain concept was not tested at FAATC because of equipment problems, but it was possible to obtain an initial evaluation of its potential to improve performance using precise data recorded at one of the FAATC test pads using the high-speed Data Acquisition Subsystem (DAS) which was built to support the ASDE-3 tests. Although not part of the original test plan, an initial evaluation of the adaptive clutter threshold technique was made using the same data. This report also delineates several questions which need empirical resolution at FAATC prior to the production procurement of the ASDE-3.

OBSERVED RAIN EFFECTS ON RADAR PERFORMANCE

Figure 1 shows attenuation due to rain observed using a small target (o.4m^2) at the test pad at 4846 feet range. The attenuation increases with rainfall rate so that at a rainfall rate of 15 mm/hr or more at least 6 dB of attenuation was observed. This is a significant portion of the 15 dB dynamic range of the radar display. This much attenuation would cause some small targets to be lost from the display. Therefore some compensation for attenuation due to rain is needed, at this range, for rain at or above 15 mm/hr.

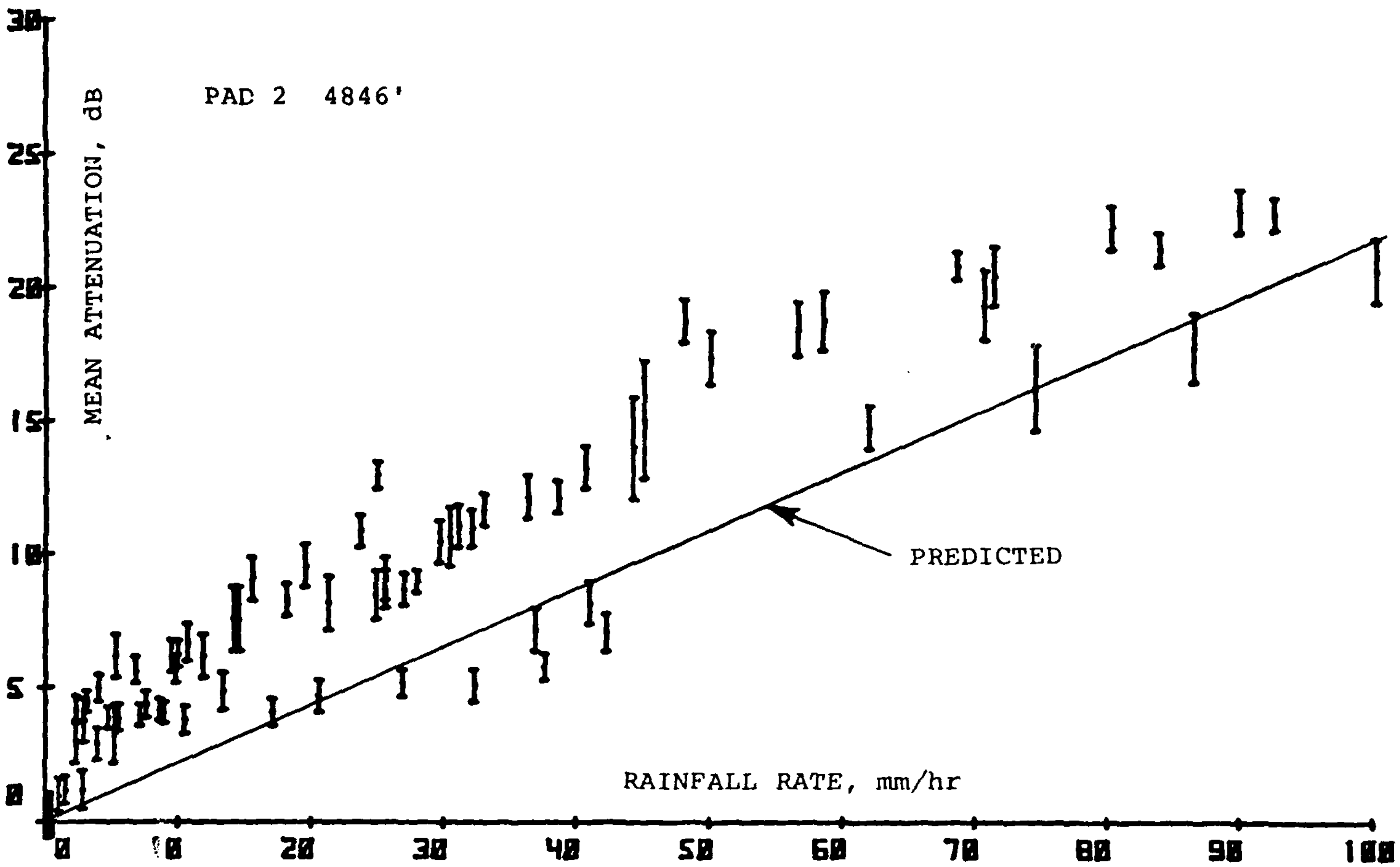


FIGURE 1. MEAN ATTENUATION VS AVERAGE RAINFALL RATE

Typically, the attenuation is worse at greater range due to the greater volume of rain traversed by the signal. Thus compensation for the attenuation would be needed at lower rainfall rates at these greater ranges.

Figure 2 shows the mean signal to noise-plus-clutter performance, as a function of rainfall rate, for the same rain observation as Figure 1. Since the display's dynamic range is 15 dB this data would seem to indicate that increased gain alone could recover the signal, without clutter, up to approximately 40 mm/hr. This is misleading, however, because the peak clutter return, as observed in the data, is significantly higher than the mean clutter and would appear on the display at much lower rainfall rates than 40 mm/hr, at this range.

Above 40 mm/hr even the mean noise plus clutter was observed to be within 15 dB of the small target. However, the S/N+C ratio remains significant even for very heavy rain, the extreme being 3 dB at 100 mm/hr. This suggests that a *threshold established* above the mean clutter but below the smallest desired target level would remove most (not all) of the clutter and enhance target detectability. This is predicated on the assumption that sufficient gain is available to compensate for the rain attenuation and restore the target return level.

Figure 3 shows the observed behavior of the clutter itself. The mean clutter return at 4846 feet increases to approximately 5 dB above noise at a rainfall rate of 20 mm/hr, and decreases, but remains above noise up to rainfall rates of 100 mm/hr. This behavior implies that at this range the increase in clutter return caused by an increase in the rainfall rate is greater than the increase in attenuation caused by that same change in rain rate, as long as the rainfall rate is less than 20 mm/hr. For rainfall rates greater than 20 mm/hr an increase in rainfall rate causes a greater increase in attenuation than in clutter return. According to the data in Figure 2, the target remains at least 3 dB above the mean clutter returns at this range, up to a rainfall rate of 100 mm/hr.

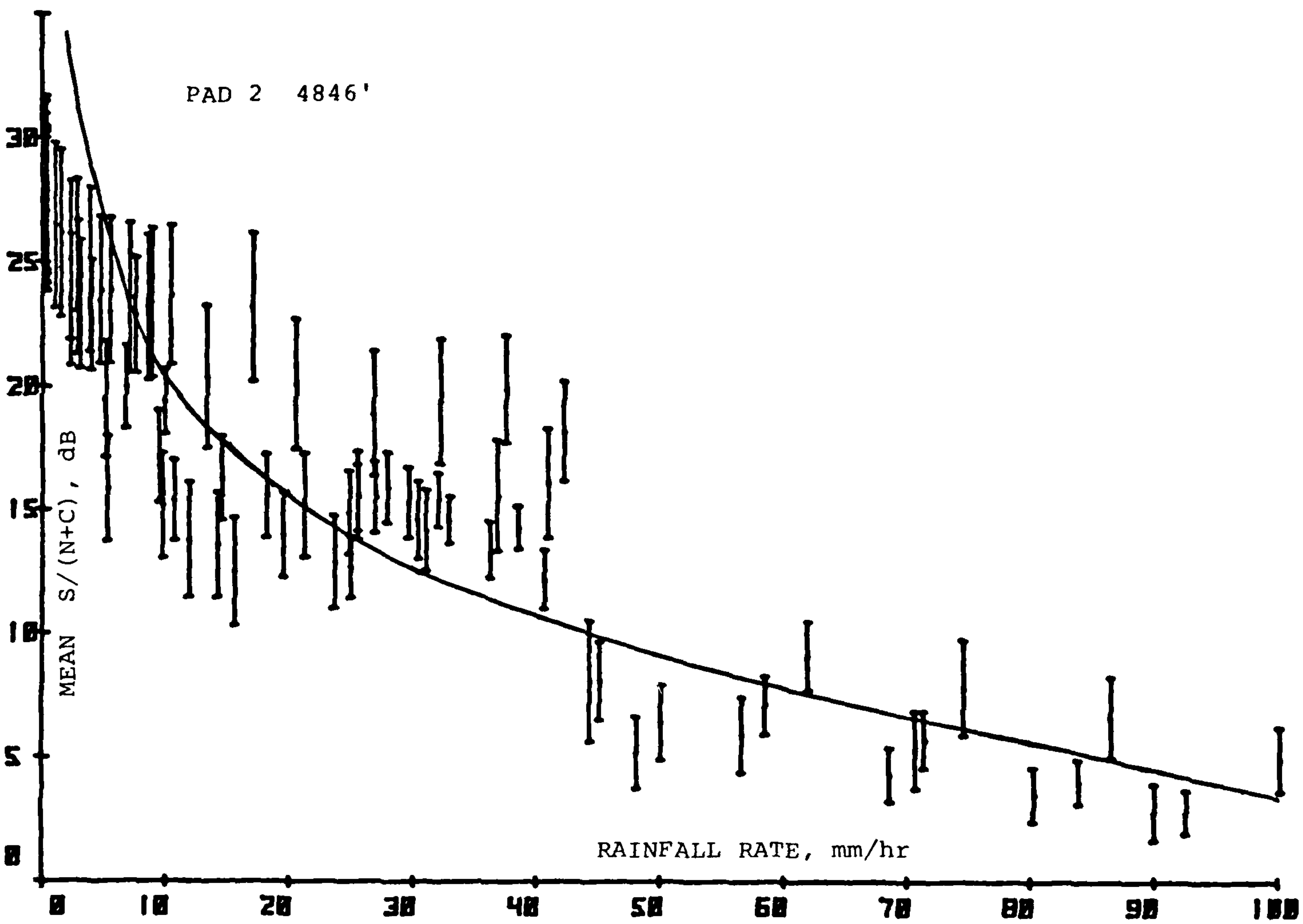


FIGURE 2. MEAN SIGNAL TO NOISE-PLUS-CLUTTER VS AVERAGE RAINFALL RATE

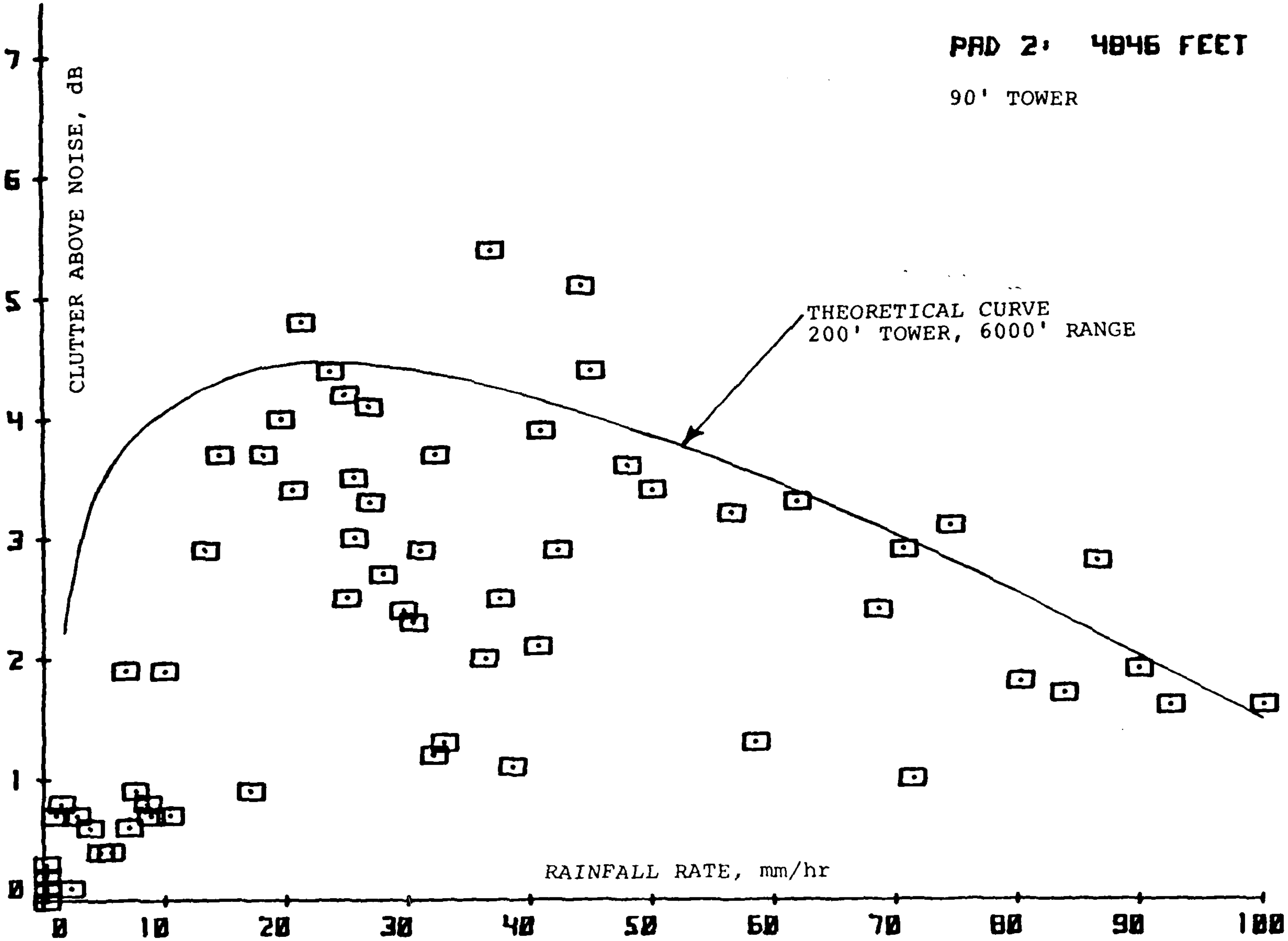


FIGURE 3. MEAN CLUTTER ABOVE NOISE VS AVERAGE RAINFALL RATE
(INCLUDES ATTENUATION EFFECTS)

In the discussion on Figure 2, above, it was mentioned that the peak clutter return observed at a given rainfall rate was significantly higher than the mean clutter return. To understand why this is so, consider Figure 4 which gives one sample of clutter return distributions at 73 mm/hr. The Figure shows the peak being 1.5 dB above the mean for frequency agility operation and 4.2 dB above the mean for fixed frequency operation. The true peak would actually be higher than this, however, because these distributions are based on sampling over a small region which contains only about 100 spatiallv independent samples. Thus a threshold established at the peak level shown here would represent a false alarm rate of 1 in 10^{-2}

The reason for using frequency agility is also evident from Figure 4. It is clear that a target detection threshold could be put about 3 dB lower (in this one example) and obtain the same false alarm rate (1 in 10^{-2}). This would allow detection of smaller targets. If these plots could show the cutoff points for false alarm rates of 10^{-6} a much greater lowering (improvement) in detection threshold placement would be observed.

If clutter becomes visible when the radar return is amplified to compensate for attenuation due to rain, a threshold can be applied to the radar signal to remove clutter from the display. If the threshold were applied at the level of the mean clutter return and that mean level were within the dynamic range of the display, approximately 50% of the area would still show 'false alarms' (visible clutter returns). If the threshold were raised, the probability of false alarm (P_{fa}) would go down.

Figure 5 shows P_{fa} as a function of threshold location relative to the mean of the two distributions of Figure 4.

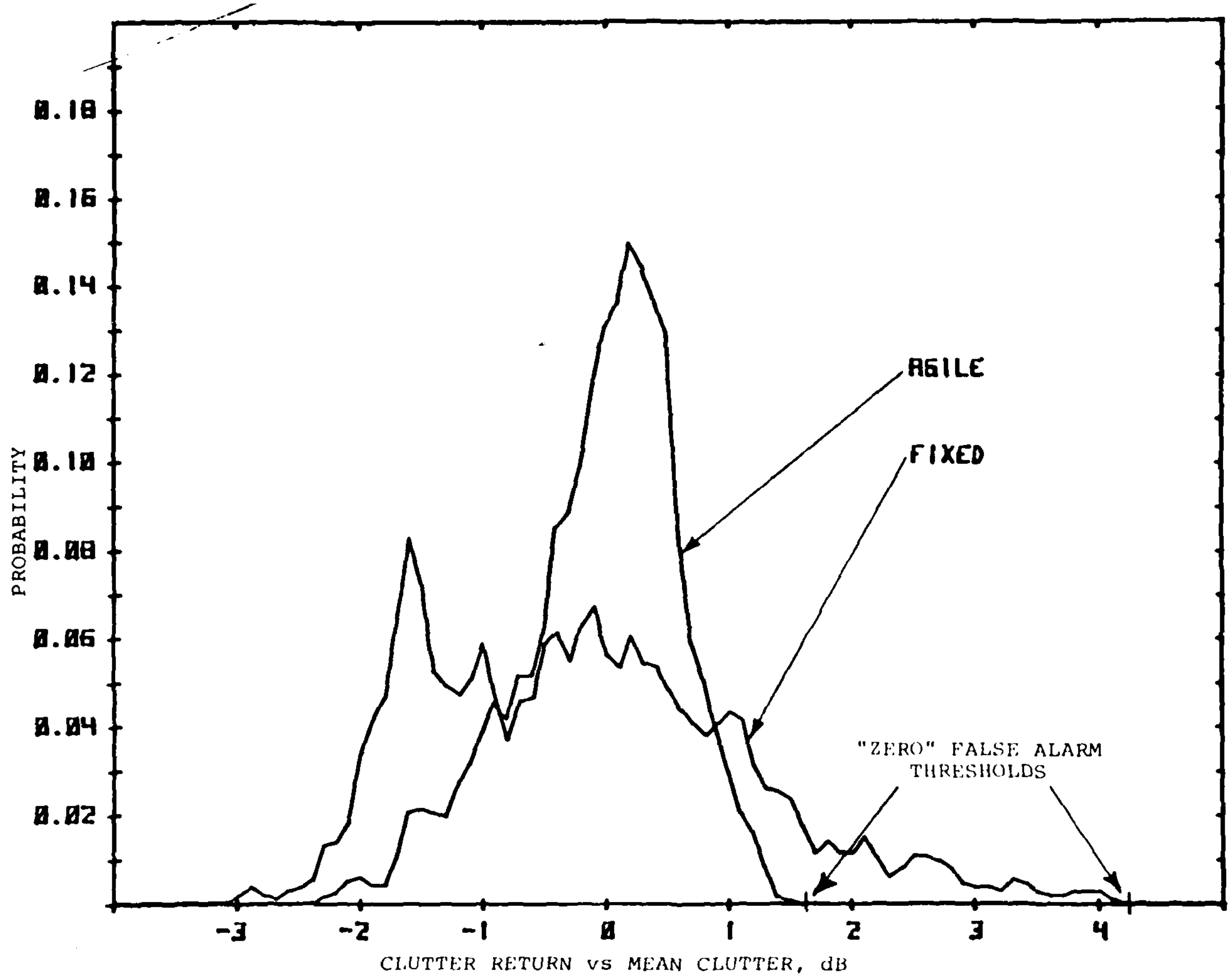


FIGURE 4. EXAMPLE OF PROBABILITY DISTRIBUTIONS OF RAIN CLUTTER RETURNS, FOR FIXED FREQUENCY AND FREQUENCY AGILITY AT 73 mm/hr

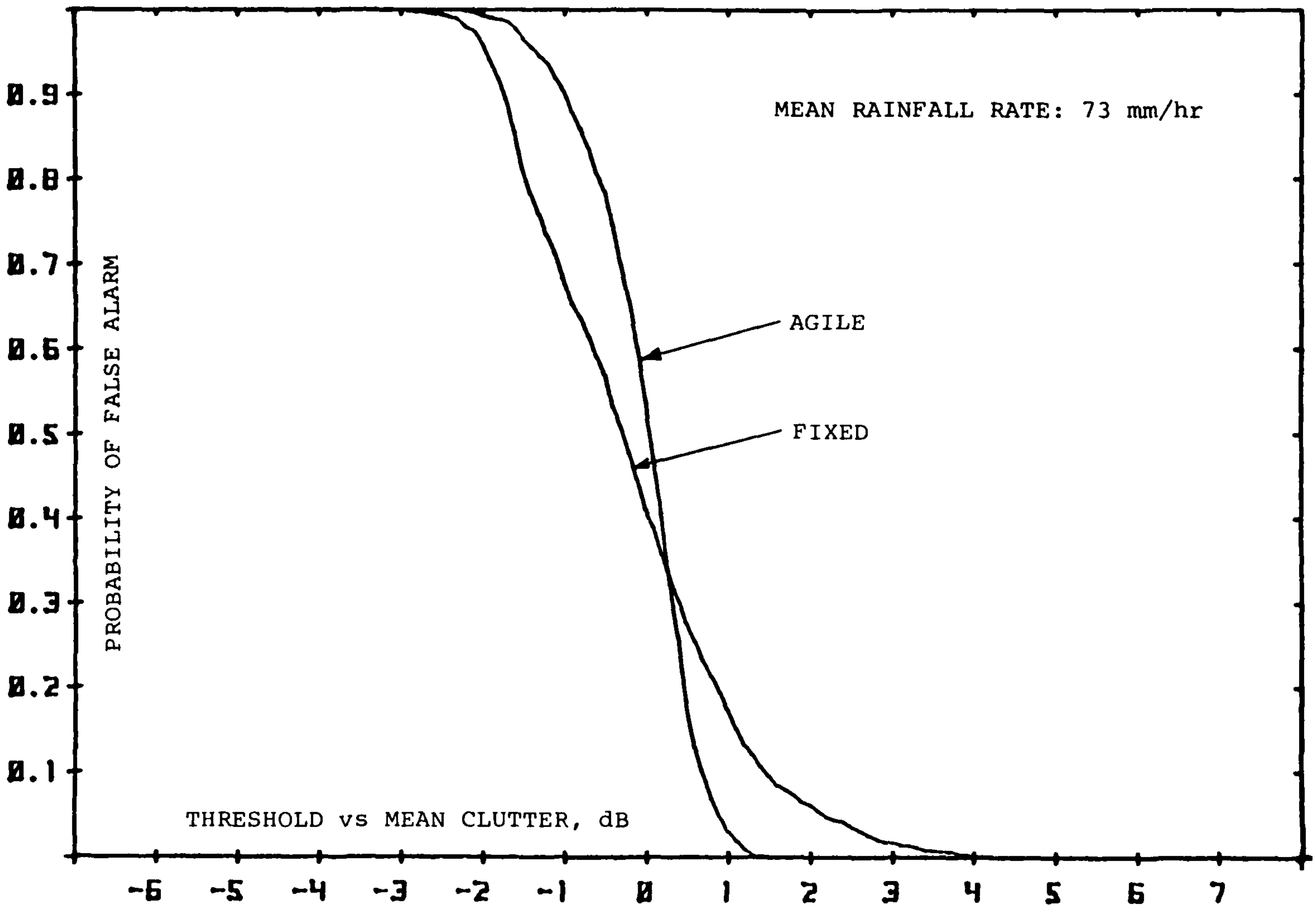


FIGURE 5. EXAMPLE OF PROBABILITY OF FALSE ALARM VS DETECTION THRESHOLD LOCATION FOR FIXED FREQUENCY AND FREQUENCY AGILITY AT 73 mm/hr

PROCESS USED FOR EVALUATION OF ADAPTIVE GAIN AND CLUTTER THRESHOLDING

Since the receiver and data acquisition subsystem (DAS) used in the ASDE-3 engineering model tests both had more than 30 dB of dynamic range and since the display has 15 dB of dynamic range, it was possible to off-line process the DAS data to simulate the display as it would have appeared with extra gain applied to compensate for the attenuation due to rain. The upper curve in Figure 6 shows how the target return was attenuated as the rainfall rate increased. The smaller vertical bars i~ Figure 6 that move down to follow the upper curve show how the range of data displayed was shifted, via data processing, to kee~ the target return constant in the processed output which simulated the display.

The bottom curve in Figure 6 shows that the mean noise-plus-clutter increases above system noise and then decreases with increasing rainfall rate, similar to Figure 3. The peak noise-plus-clutter is substantially above the mean clutter (as noted in the discussion for Figures 4 and 5 above), but it remains below the target level up to 80 mm/hr. The mean clutter is well below the target level for all measured rainfall rates.

The diagram in Figure 6 suggests that the use of adaptive gain and clutter thresholding may be able to restore 'no rain' appearance to the display even at rainfall rates of 60 mm/hr or more. It also suggests that it should be possible to at least partially recover the targets, with clutter, up to rainfall rates of 99 mm/hr - at 4846 feet range. The quality of target recovery will be a function of the spatial uniformity of the rain and the density of sample points across the field.

The adaptive gain could actually be implemented in a manner similar to this off-line processing used for evaluation. The radar video could be amplified after it exits the receiver but before it reaches the display. Alternatively, the adaptive gain could be implemented with a hi~h-gain receiver, using the receiver gain alone

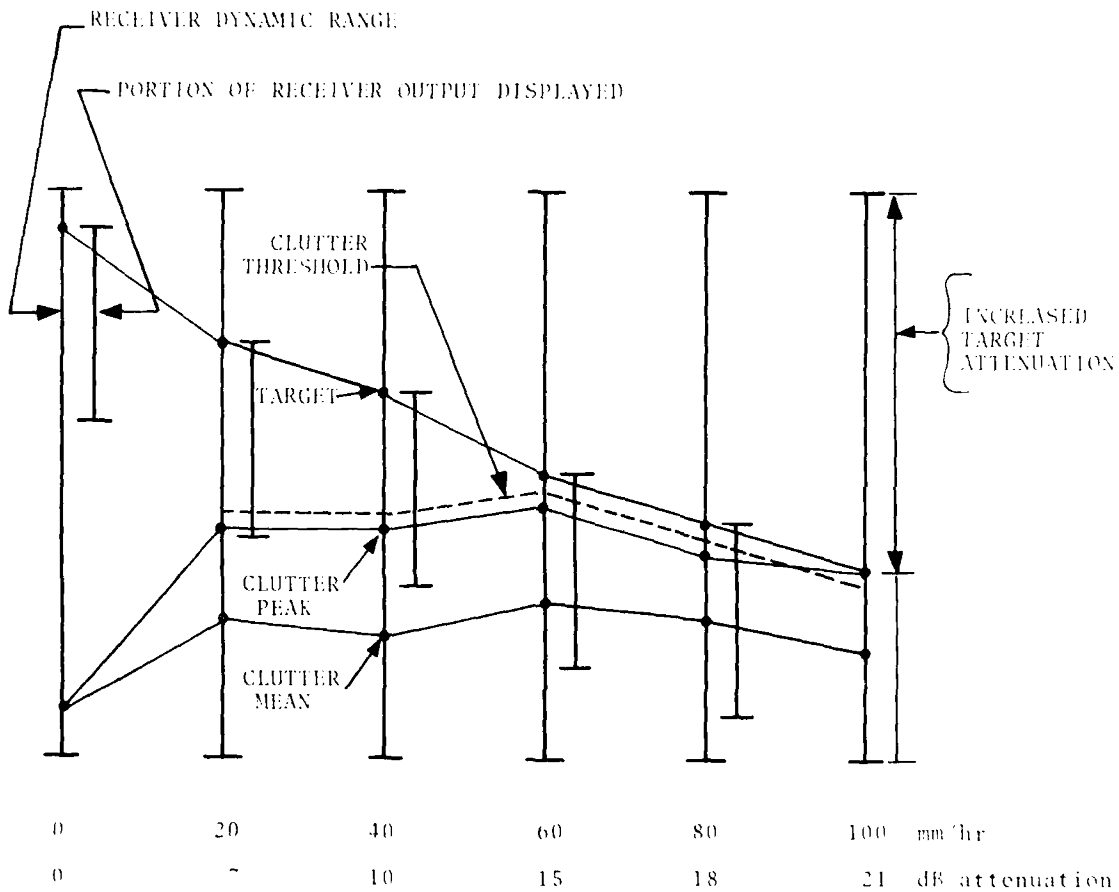


FIGURE 6. COMPENSATION FOR RAIN EFFECTS ON ASDE-3 VIA DISPLAY INPUT ADJUSTMENT
(USING WIDE RECEIVER DYNAMIC RANGE AND ADDING A CLUTTER THRESHOLD)

to compensate for attenuation. (This was the original intent for the ASDE-3 Engineering Model.) Figure 7 shows the same data as in Figure 6, re-arranged as if receiver gain alone were used to compensate for attenuation due to rain.

POTENTIAL PERFORMANCE OF ADAPTIVE GAIN CLUTTER THRESHOLDING

Figure 8 shows the potential performance of the adaptive gain and clutter threshold process in recovering targets for varving rainfall rates. Each row covers forty seconds of observation and the rain rate is the average over that period. The left half of the table shows the performance with adaptive gain processing alone and the right half shows the same data with both adaptive gain and clutter threshold processing. This data was selected for small variation in rainfall rate over the period of observation.

The change in performance for varying rainfall rate is not smooth because there is a limited quantity of data. However, a definite trend is observable. For example, 'full recovery', or restoration of 'no rain' appearance, using adaptive gain and clutter threshold occurs 100% of the time for all rainfall rates up to 40 mm/hr. At higher rates the percent of total recovery drops steadily till it is zero at 99 mm/hr. Also, examining the "total recovery - no clutter" columns it may be noted that the addition of clutter threshold processing raises the total recovery performance from 10% to 60% at 55 mm/hr.

Since the quantity of data is small these observations are suggestive rather than conclusive. Adaptive gain appears to have great benefit and clutter thresholding offers promise of further improvement. The amount of improvement obtained from clutter thresholding and the rainfall rate at which it begins are not certain. However, Figures 9 through 14 show that the physical improvement of the display appearance obtained by thresholding-out clutter may be greater than seems implied by the numbers in Figure 8.

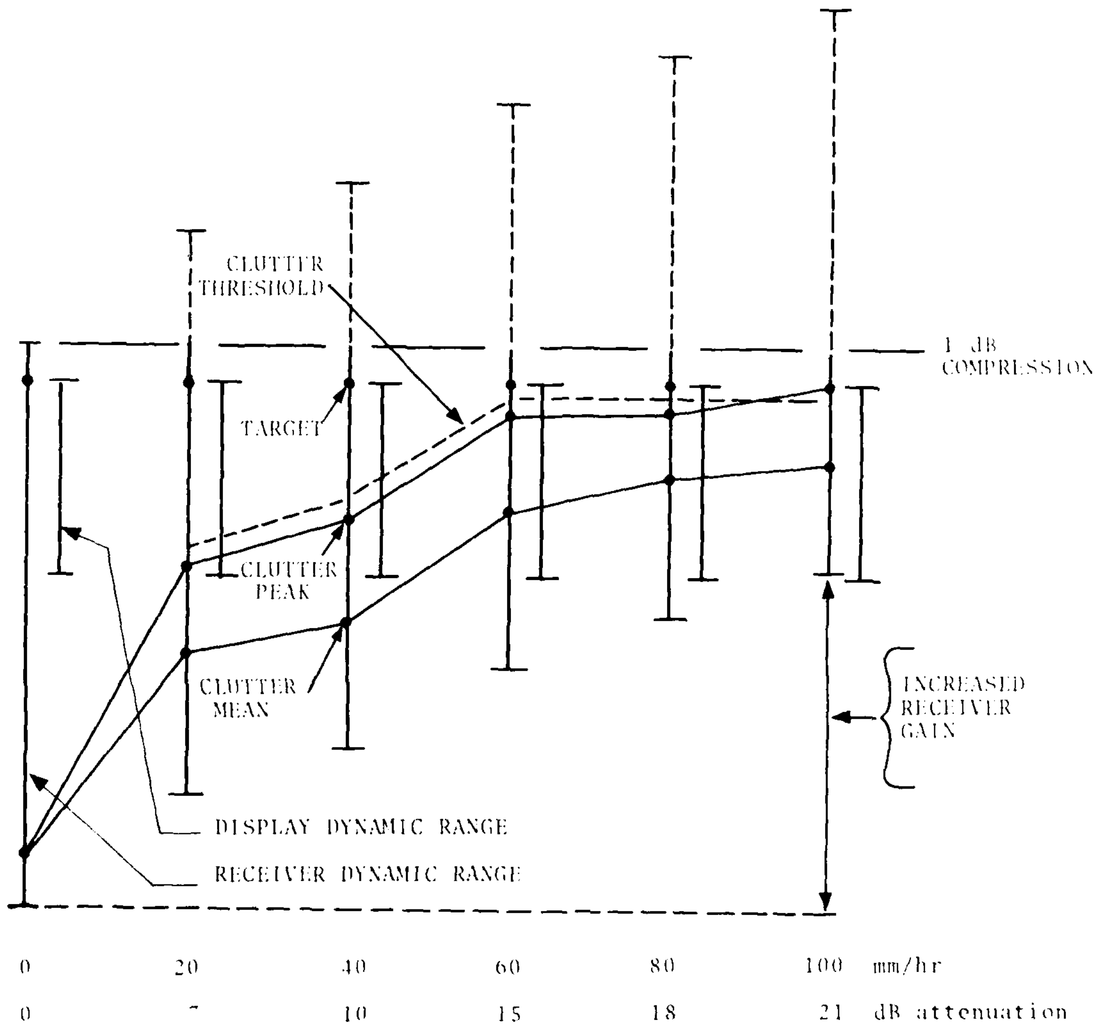


FIGURE 7. COMPENSATION FOR RAIN EFFECTS VIA INCREASING RECEIVER GAIN AND ADDING A CLUTTER THRESHOLD

AVE RAIN RATE, MM/HR	TARGET RECOVERY WITH RAIN GAIN ALONE				TARGET RECOVERY WITH RAIN GAIN & CLUTTER THRESHOLD			
	FULL		PART	NONE	FULL		PART	NONE
	CLUTTER REMOVED	CLUTTER SERIOUS			CLUTTER REMOVED	CLUTTER SERIOUS		
11	100%	0%	0%	0%	100%	0%	0%	0%
18	90	10	0	0	100	0	0	0
30	100	0	0	0	100	0	0	0
39	100	0	0	0	100	0	0	0
44	0	80	20	0	80	20	0	0
55	10	50	30	10	60	0	30	10
73	0	10	20	70	10	40	40	10
76	0	30	20	50	10	30	30	30
99	0	0	50	50	0	30	40	30

(RANGE = 4846 Feet)

FIGURE 8. TARGET DETECTION PERFORMANCE (FREQUENCY AGILE) VS RAINFALL RATE SIMULATING THE 'ADAPTIVE GAIN' & 'CLUTTER THRESHOLD' FUNCTIONS USING OFF-LINE PROCESSING

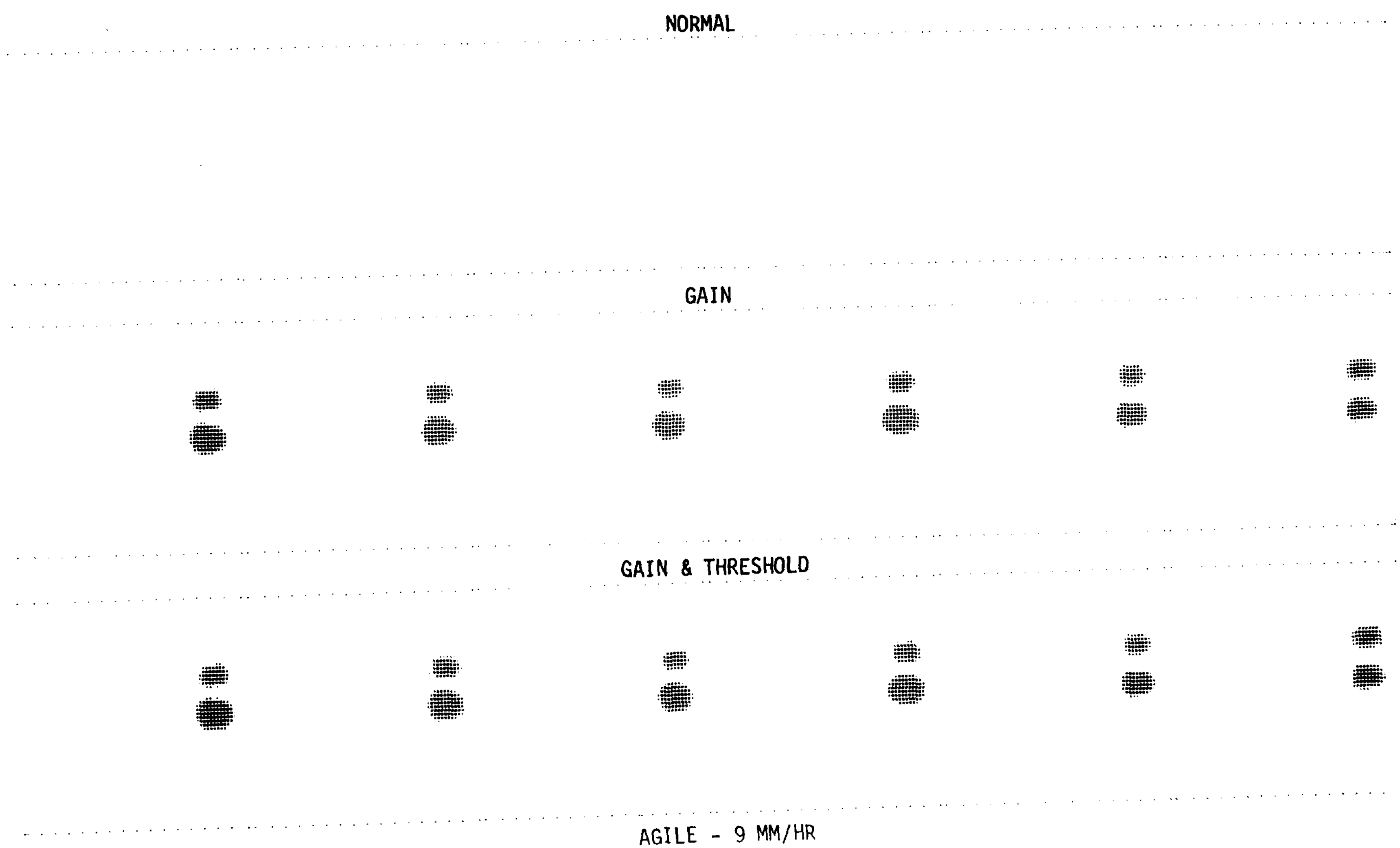


FIGURE 9. RESTORATION OF RADAR TARGETS ATTENUATED BY RAIN AT 9 MM/HR

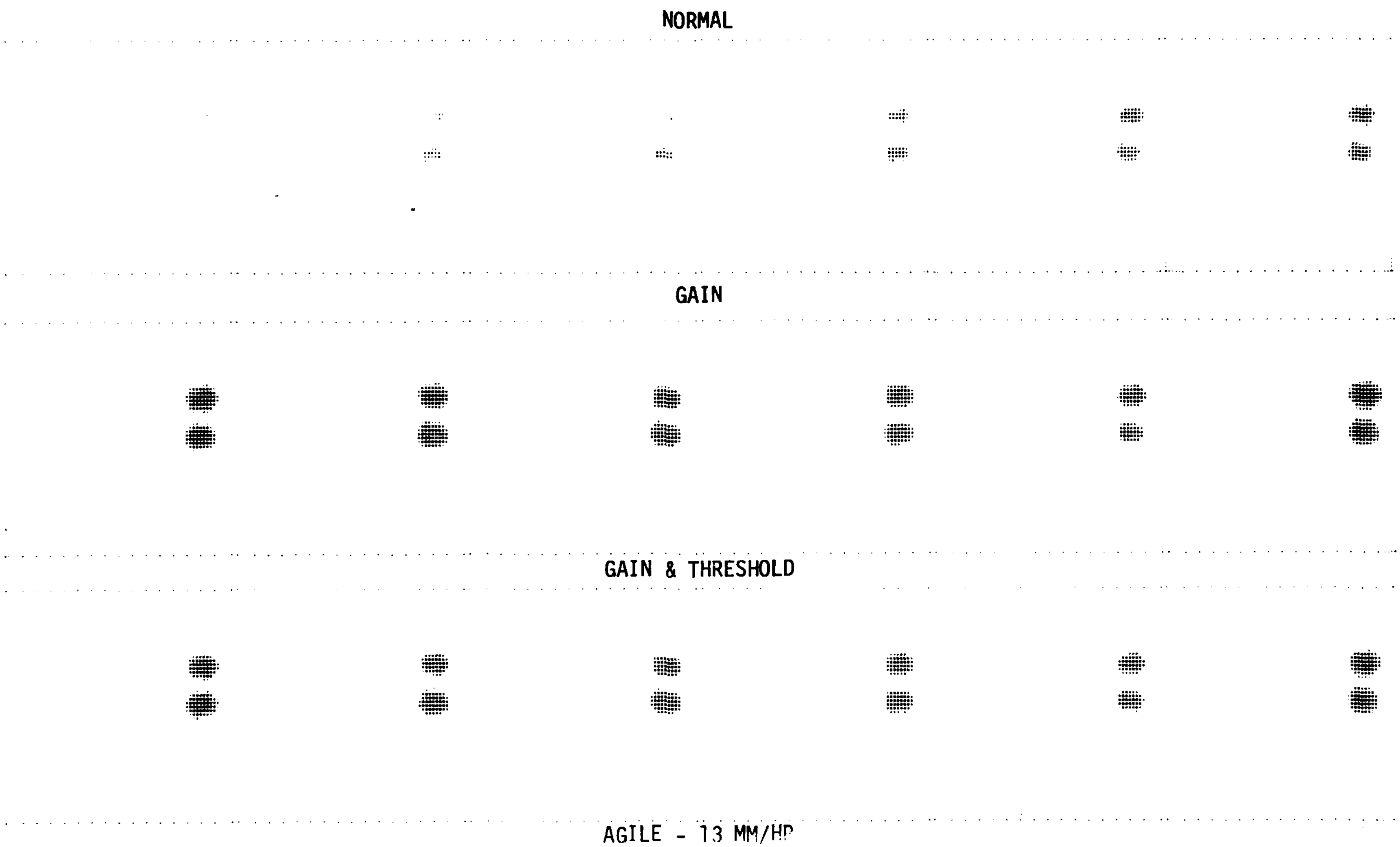


FIGURE 10. RESTORATION OF RADAR TARGETS ATTENUATED BY RAIN AT 13 MM/HR

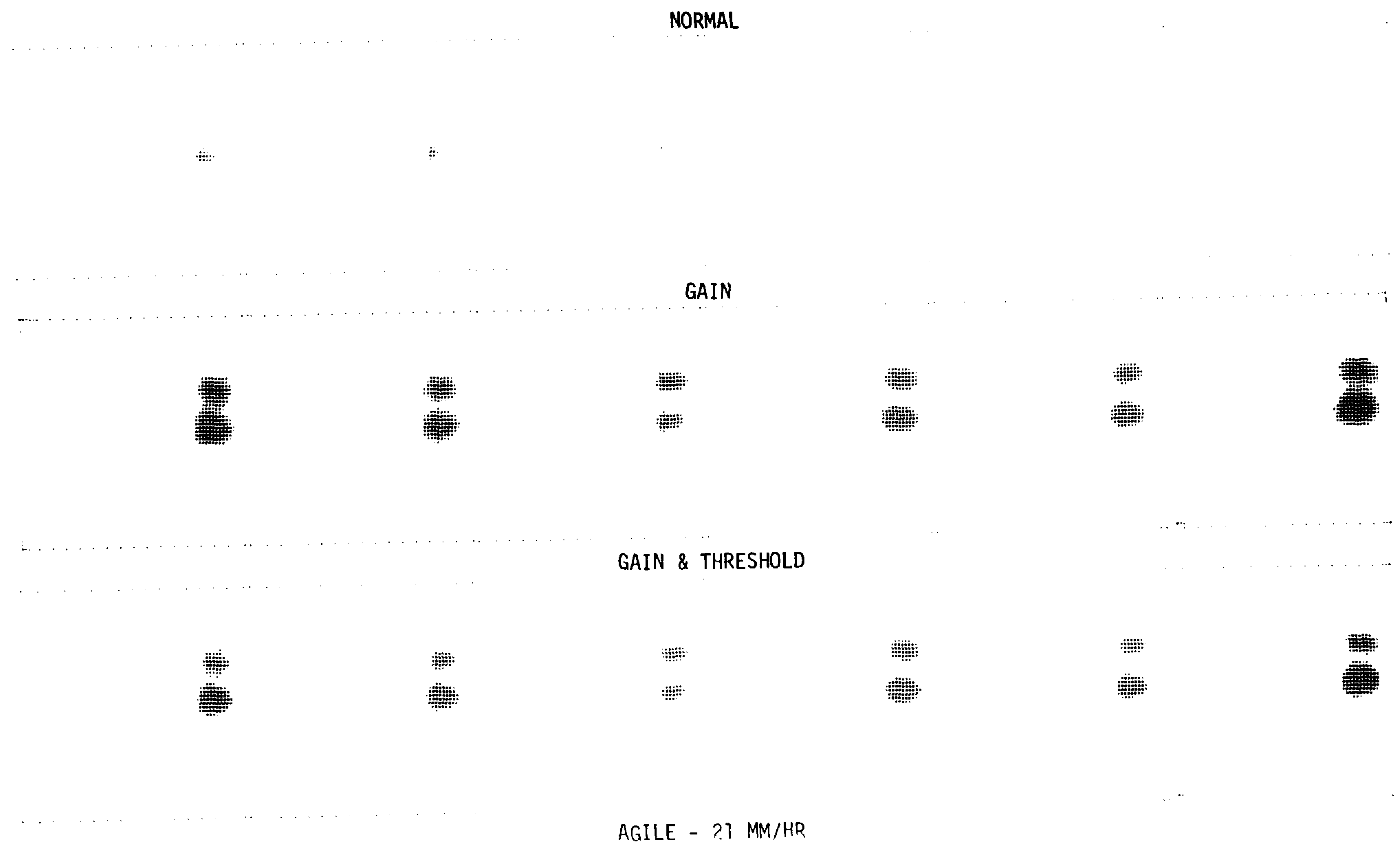


FIGURE 11. RESTORATION OF RADAR TARTETS ATTENUATED BY RAIN AT 21 MM/HR

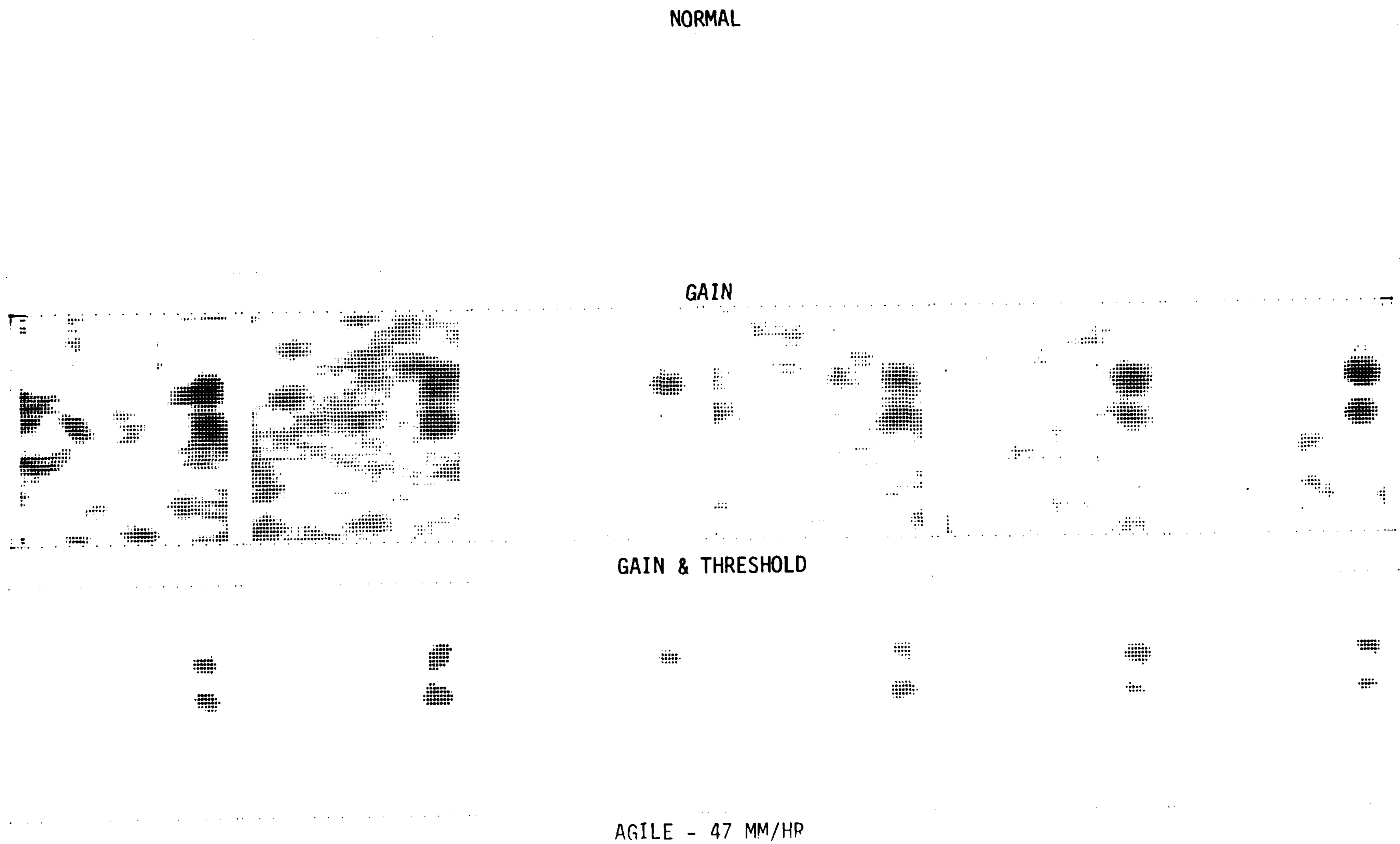


FIGURE 12. RESTORATION OF RADAR TARGETS ATTENUATED BY RAIN AT 47 MM/HR

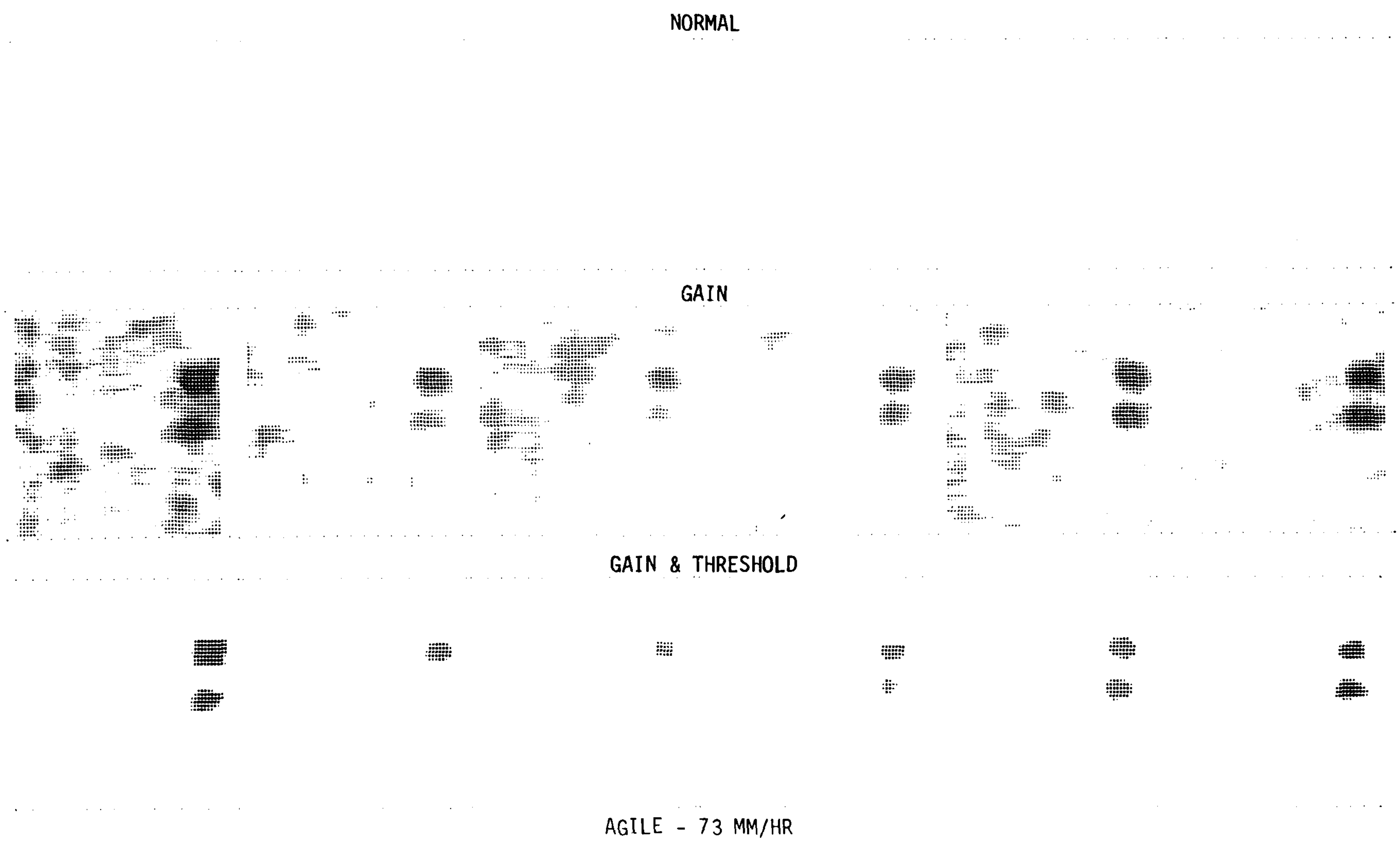


FIGURE 13. RESTORATION OF RADAR TARGETS ATTENUATED BY RAIN AT 73 MM/HR

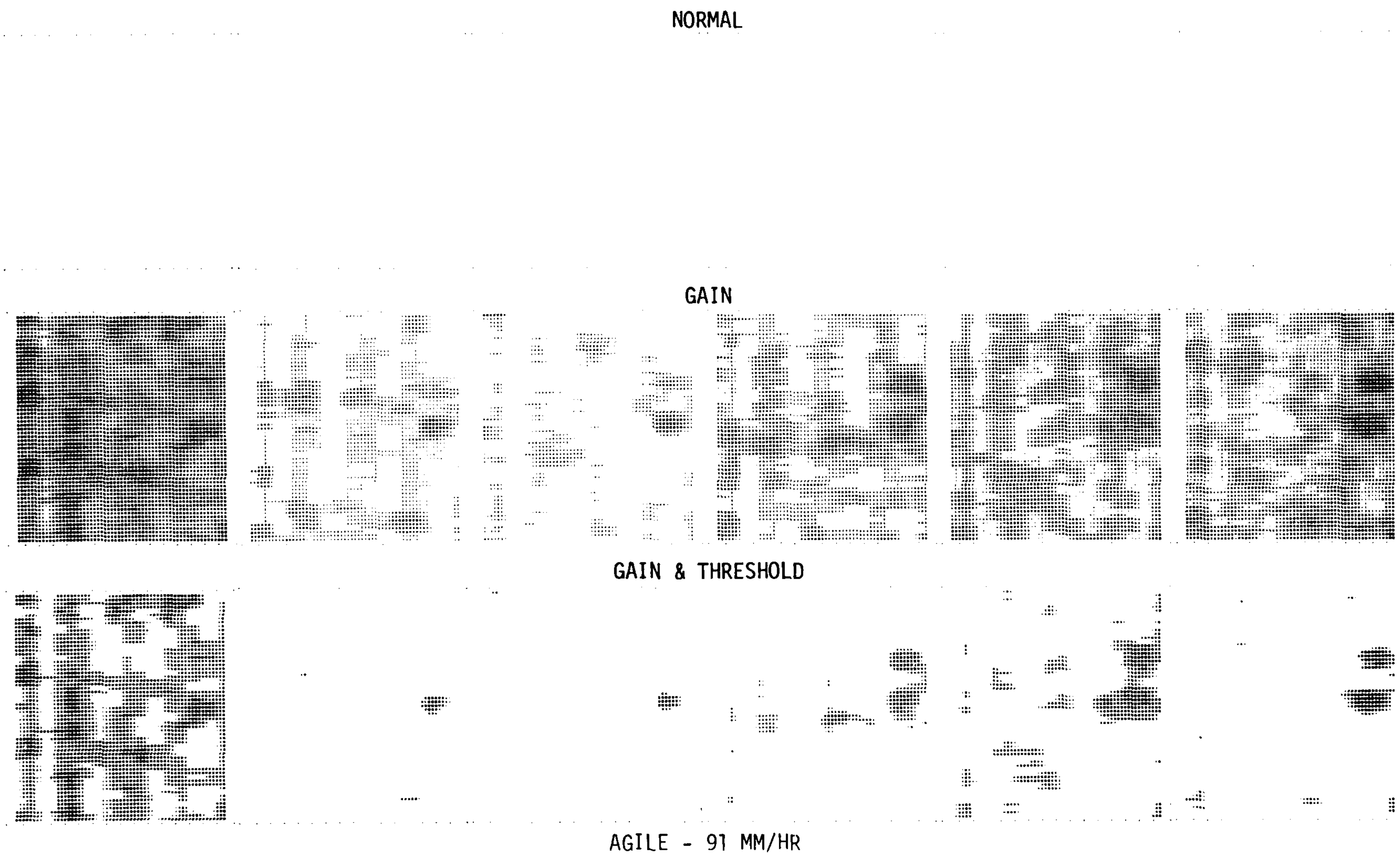


FIGURE 14. RESTORATION OF RADAR TARGETS ATTENUATED BY RAIN AT 91 MM/HR

Figures 9 through 14 simulate, from DAS data (in reverse tone), how the display, enhanced by adaptive gain and clutter threshold processing, would appear for five rainfall rates from the table in Figure 8. The frames, left to right, are four seconds apart in time. The radar is in frequency agile mode. The image is of two small targets (0.4 m^2) spaced about 30' apart at 4846 feet range. The top row of frames on each figure shows how the targets would appear with the display set 'normally', that is, with fixed gain and no threshold. The middle row contains the same data but processed to show how the display would appear with the adaptive gain function added to compenstate for attenuation. The bottom row also contains the same data, but processed to show how the display would appear with both adaptive gain and clutter thresholding.

By comparing the top rows of frames in Figures 9 through 14 it can be seen that targets of this size are almost attenuated out of the display at 18 mm/hr at this range. At 44 mm/hr the targets are no longer discernible due to the attenuation. This can also be seen in Figure 6 by comparing the target level at 44 mm/hr to the location of the lower end of the display dynamic range at 0 mm/hr.

Comparison of the middle rows of frames in Figures 9 through 14 shows that the addition of adaptive gain restores the targets to the display but also makes rain clutter visible. The bottom rows of frames show that the addition of clutter thresholding to the adaptive gain function removes almost all clutter and leaves just targets, up to rainfall rates of about 55 mm/hr. At 99 mm/hr the clutter threshold also removes much of the clutter but the attenuation is so great that the target returns are sometimes just above the system noise level and the clutter threshold then falls below the system noise level. This situation appears in frames 1 and 5 of Figure 13. (The vertical streaks are due to a one-count offset in one of the four A to D converters, which becomes visible near system noise level.)

Comparison of the bottom rows of frames in Figures 9 through 14 also shows that sometimes one target disappears while the other does not. Figures 11 and 12 show this happening to the lower target. Figure 14 shows it happening to the upper target. The targets were low to the ground, mounted on stiff fiberglass tubes, so it is unlikely that this effect is due to target motion. Therefore, it was concluded that regions of high attenuation can be as small as 30 feet in diameter. These regions would not cause total loss of large targets (i.e., commercial aircraft) at this range if adaptive gain and clutter thresholding were in operation, but would occasionally cause these targets to break up. Further examination of thiis variability of attenuation is in order.

Figure 14 shows that at this range and rainfall rate the recovery of these targets is limited not by the clutter but by the lack of sufficient gain in the system to bring the targets well above the system noise level.

NOVEL TECHNIQUE FOR MEASURING RAIN CLUTTER

The concept of using a threshold to remove rain clutter is not new. The problem has been to obtain a reliable measure of the rain clutter. If data on rain clutter were being sampled on a runway or taxiway there would be times when an aircraft or vehicle would confuse the reading by passing through the sample area. If data on rain clutter were being sampled (as it was for this test of the ASDE-3 Engineering Model Radar) by collecting data from a large, specially prepared, asphalt pad (about 150 feet square), the cost of installing and maintaining several such these pads on each airfield would be prohibitive. Thus a better method for measuring rain clutter is needed before it could be practical to implement a clutter thresholding technique.

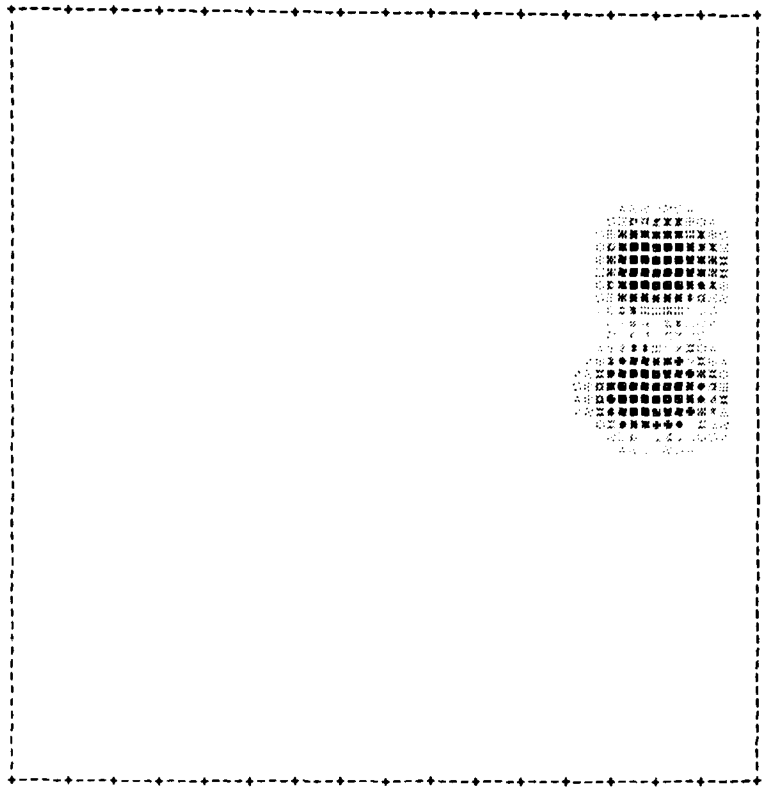
Figure 15 shows, at the left, how the targets and test pad in Figures 9-14 appear on the 'normal display' in clear weather. If the data is reprocessed to show

all returns above system noise, the grass returns at the edges of the pad appear, (right frame, Figure 15). These grass returns are about 12dB above system noise level. By examining Figure 6 it can be seen that at rainfall rates of 20 mm/hr the peak clutter-plus-noise returns are about 12 dB above system noise level whereas the target (and hence also the grass) returns have been attenuated by about 7 dB (in this data). Thus when the rain becomes heavy enough to cause clutter that is bright enough to be serious, the grass returns from the pad edge have been attenuated to about 7dB below the peak rain clutter. This means that if a measure of the peak return is made during rain, from an area that contained low level grass returns in clear weather, this measurement will, in fact, be the peak clutter return when the rain is serious enough to merit measuring the rain clutter.

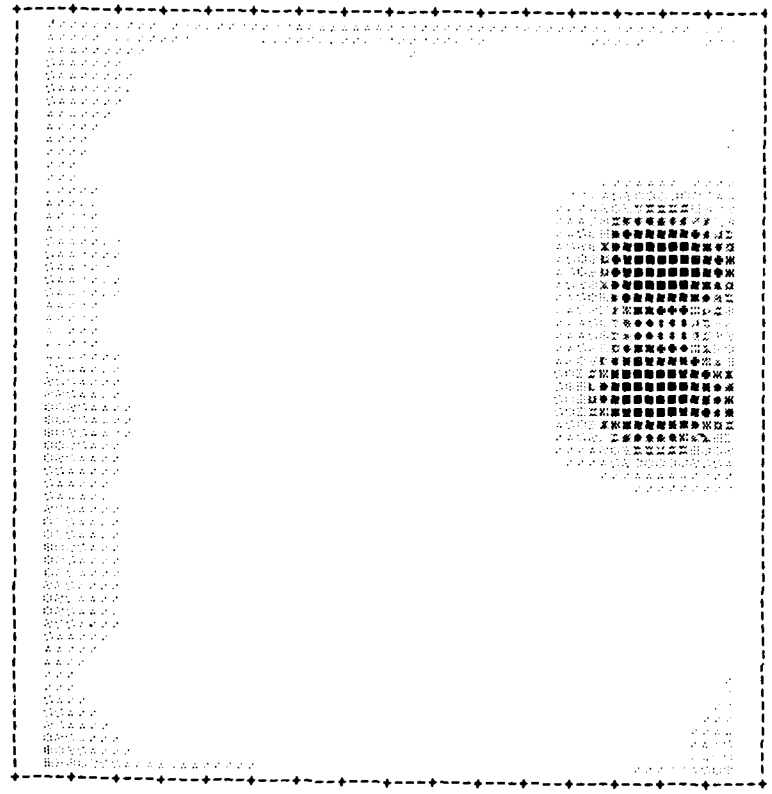
Thus, grass areas with low grass returns may be used as regions for sampling rain clutter. The clutter sampling function would only be turned on when the attenuation, measured at a reflector close to the sampling area, was high enough that the grass returns would not be predominant.

Figure 16 shows a region at about 3000' feet range, where the grass returns are higher than in Figure 15 due to the higher grazing angle. Each cell in Figure 16 covers four times the area covered by a cell in Figure 15. The aircraft images are of a Boeing 747. The triangular shaded area at the bottom center is off-runway grass.

Bright spots appear in the grassy area in Figure 16. A sample area containing one of these bright spots would not be satisfactory for measuring rain clutter. The occurrence of these bright spots is probably due to the contour of the ground and it is worth noting that the bright spots are not so bright as the aircraft. It is possible, however, to locate large areas of low return from grass, as shown by the rectangular outline in Figure 16. This rectangle covers approximately 1.25 times



NORMAL DISPLAY APPEARANCE - NO RAIN
(GRASS RETURNS ARE TOO WEAK TO
REGISTER ON THE DISPLAY)



PROCESSED TO SHOW GRASS

FIGURE 15. CLEAR WEATHER TARGET AND GRASS RETURNS

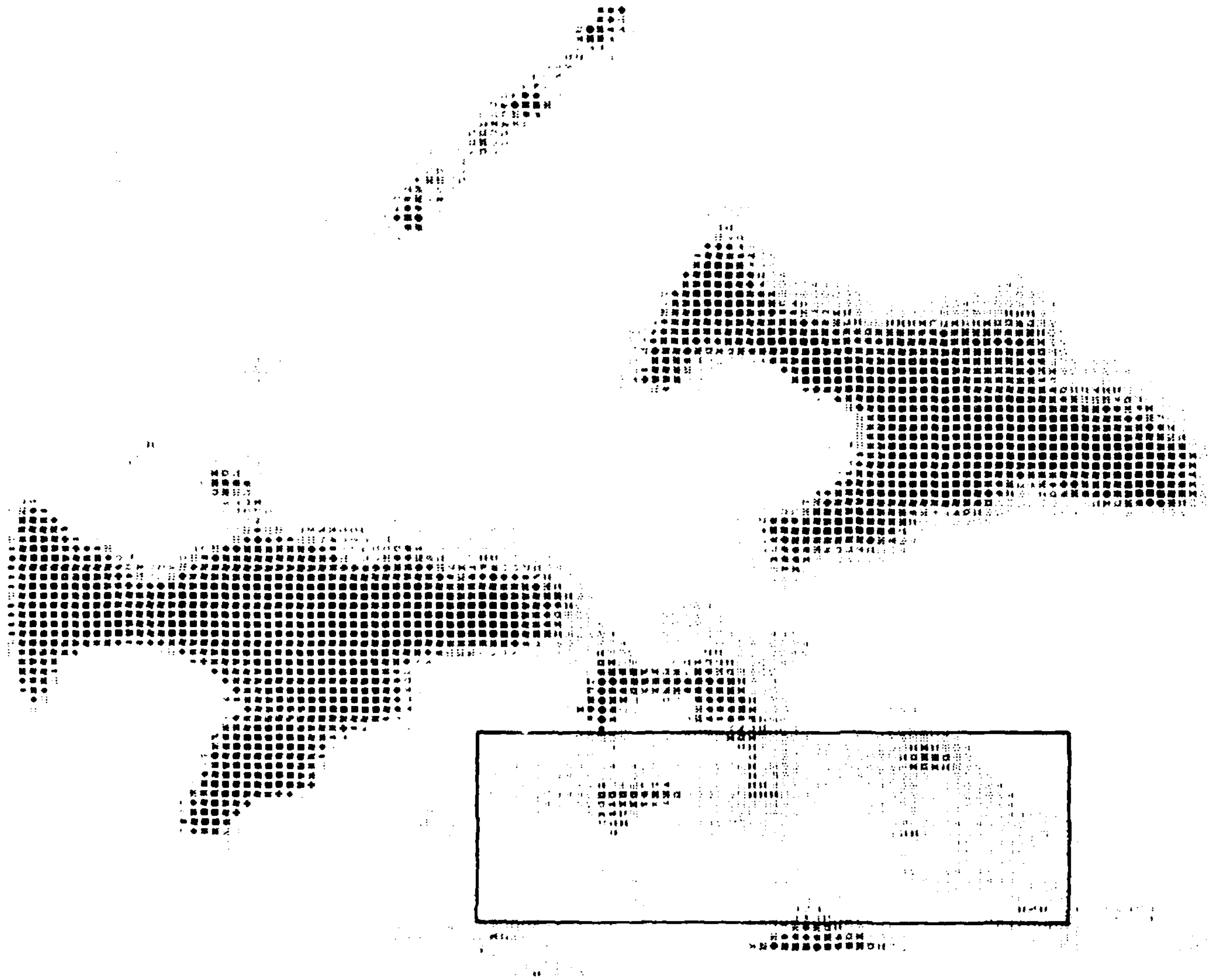


FIGURE 16. LARGE TARGET AND OFF-RUNWAY GRASS AREA AT 3000 FT, (SHOWS REGION OF LOW GRASS RETURNS SUITABLE FOR SAMPLING RAIN CLUTTER)

the area shown in the Figure 15. Thus Figure 16 suggests that it should be possible to find a satisfactory grass area in any region of the field at or beyond 3000 feet.

Grass areas with low radar returns, when caused by low terrain or shadowing should remain areas of 'low return' regardless of grass height, cut, etc. Since the rain clutter comes from a volume at the same range whose height is approximately that of the ASDE tower its return is not affected by the termin. This suggests that it might be possible to construct ideal clutter sampling areas by simply erecting a low reflective fence across the near edge of the area, taking care that its shadow does not extend into any critical areas. This possibility should be checked out using the ASDE-3 Engineering Model at FAATC.

TECHNIQUE FOR IMPLEMENTING ADAPTIVE GAIN

The additional gain necessary to compensate for the rain attenuation would be applied over 32 cells in range, out to 18,000', and over 128 azimuth sectors. The gain value for each cell would be determined by real-time interpolation from the attenuation measured at adjacent reflectors during the last scan. A possible layout of the reflectors is shown in Figure 17.

It should be noted that the azimuthal dimension of the gain cells would vary from 221' wide at 4500' to 442' wide at 9000' to 884' wide at 18,000'. The range dimension of the gain cells would be constant at 562', as proposed by the above contractor. Although the dimensions of these cells are large, smaller cells would only be possible if more reflectors were installed to obtain better sampling of the rain attenuation.

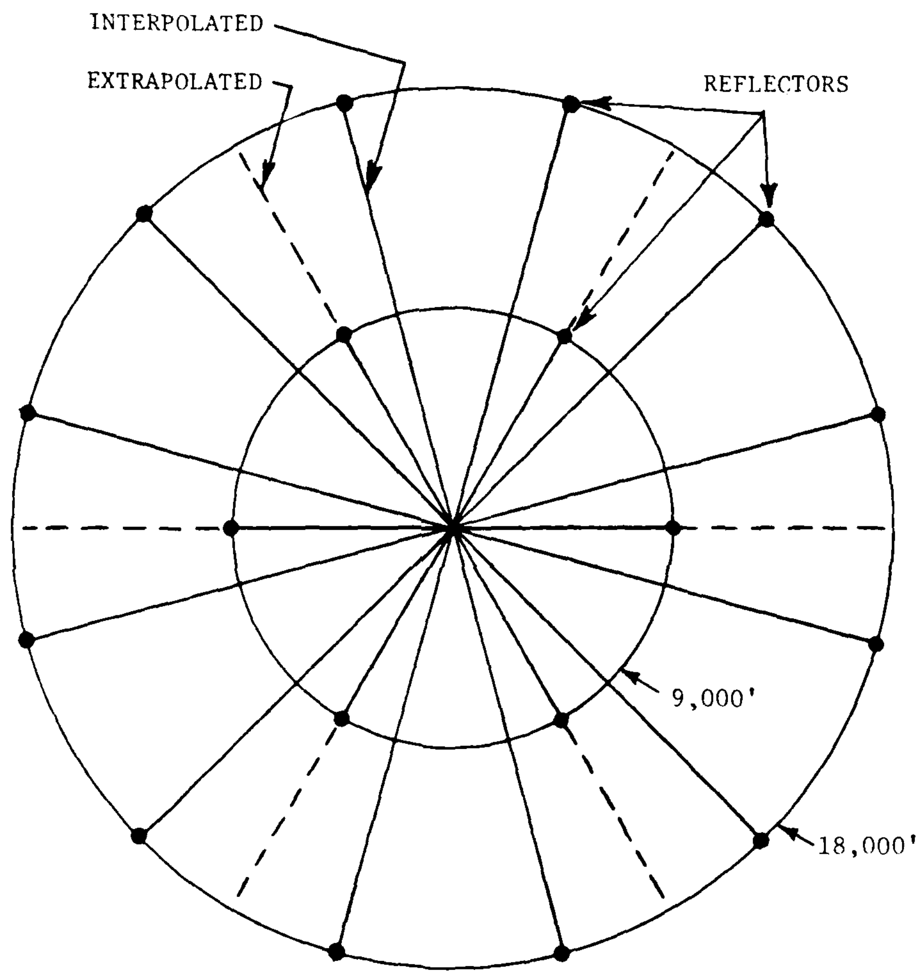


FIGURE 17. POSSIBLE LAYOUT OF REFLECTORS FOR 'ADAPTIVE GAIN' - 18,000' RADIUS

As shown in Figures 6 and 7 the rain gain function could be implemented either by amplifying the output of a wide-dynamic-range receiver or by controlling the gain of a high gain receiver.

The measurement of a target return should involve averaging samples taken over as many pulses as are contained in the frequency agile pattern, (since the return may vary slightly with frequency step due to ground bounce) if this is possible within the 3 dB antenna beamwidth.

It is also possible that small stable objects on the field could be used in place of some of the reflectors. This is not too likely, however, because the object would have to be permanent, stable, and have a fairly low return so it wouldn't saturate the receiver. There are probably few objects with just the right return level for this use. But this possibility should be checked at FAATC.

TECHNIQUE FOR IMPLEMENTING A CLUTTER THRESHOLD

The quantity and location of clutter sampling areas should be the same as for rain gain reflectors. The clutter threshold level would be interpolated and read out in real time over the same cells as the rain gain, see Figure 17.

The threshold would be applied at the receiver output (downstream from rain gain) cutting off transmission to the display of all signals at or below the detected level of clutter.

The sampling of clutter should take place over an area at least 100 feet square and should detect the peak clutter return. The clutter return should be measured by averaging samples taken over either the quantity of pulses in an antenna beamwidth or the quantity of pulses in the frequency agile pattern if that is smaller. It is desirable to detect the peak clutter because then the threshold will

remove all clutter returns rather than just those at or below the mean clutter level. The circuitry can be designed to limit the threshold to a preset level that is below the return for the smallest target to be detected.

If the rain is highly non-uniform between the points at which clutter is measured a threshold applied in that region could remove some desired small targets as well as clutter. Therefore, the operator must be able to shut off the threshold function at will.

HARDWARE IMPLEMENTATION

One approach to structuring the hardware to implement adaptive gain is given in block diagram form in Figure 18. A duplicate of this circuitry (excepting the sampling and output control circuits) could be used to implement the clutter threshold function. This means that including a requirement for clutter thresholding in addition to adaptive gain would add little additional cost, since much circuitry would be duplicated.

The diagram in Figure 18 shows two processors. The 'controller' would be dedicated to sequential loading of the 'window location and sizing circuits' with the location and size of the sample windows. (This function might be absorbed in the 'interpolation processor' if that processor were fast enough. It is also possible that one 'controller' could serve both adaptive gain and clutter threshold functions.)

The 'interpolation processor' would be dedicated to performing the interpolation, in real time, of the data stored in memory from samples on the previous scan, (see Figure 17). The interpolated data would be stored in the output control circuits and would be read out synchronously with the radar video to control gain or thresholding.

The 'window locating and sizing circuits' would monitor the azimuth and range location of the radar return and turn on the 'sampling circuits' at the correct times.

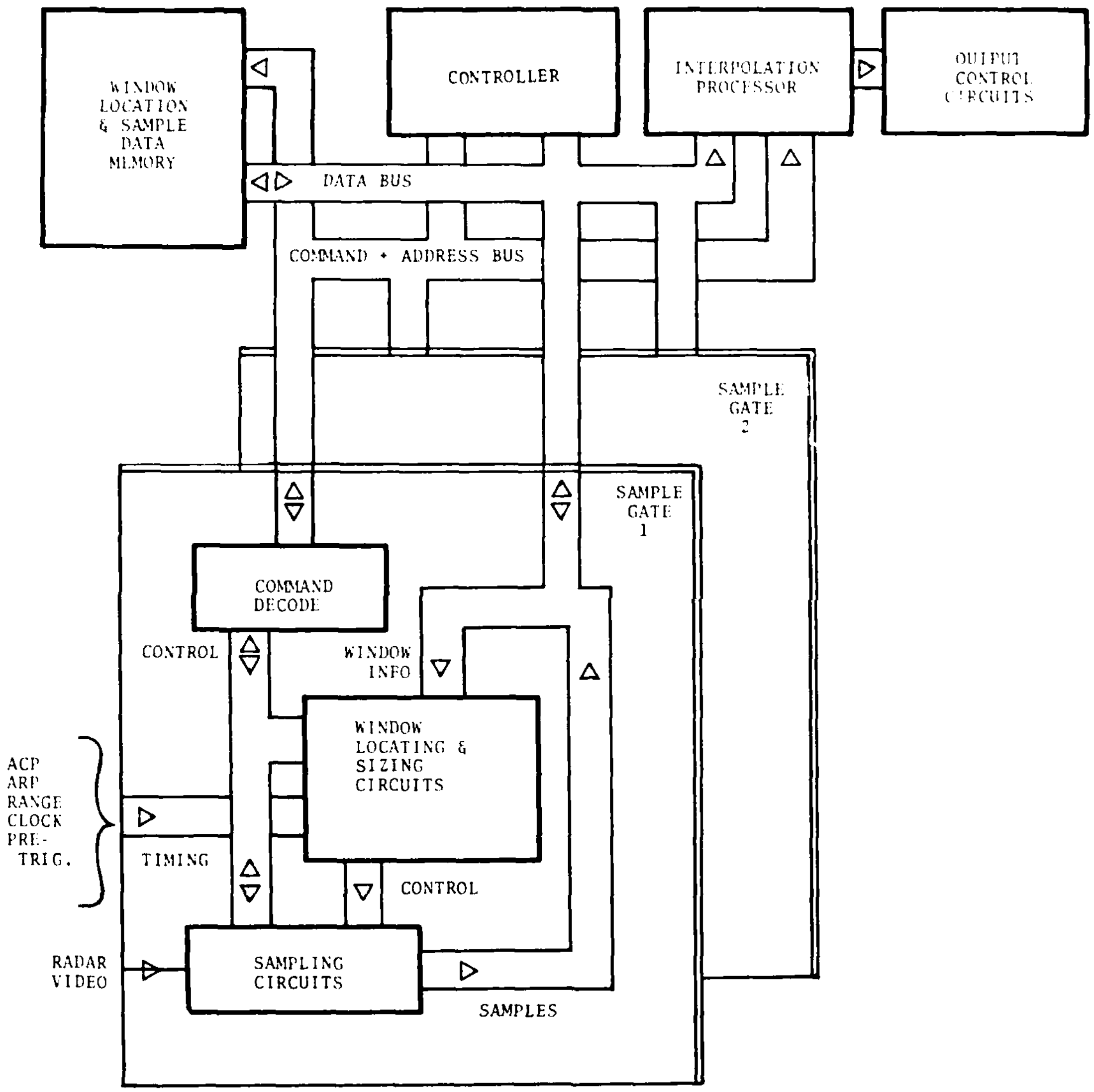


FIGURE 18. BLOCK DIAGRAM FOR 'ADAPTIVE GAIN' OR THRESHOLDING CIRCUITS

The 'sampling circuits' would differ for adaptive gain and clutter thresholding. For measuring the return from a reflector for the adaptive gain function the 'sampling circuits' would need to acquire an average return over several pulses from a given range cell. For measuring the clutter return from an area the 'sampling circuits' would need to obtain the maximum of the 'averaged' clutter returns within the sampling area. That is, each clutter return would be an average, just like the measured return from the rain gain reflectors, and the 'sampling circuits' would have to select the greatest of these averaged returns. The 'sampling circuits' would also require direct memory access capability to store the data.

PROP SED TESTS OF ADAPTIVE GAIN AND CLUTTER THRESHOLD

Empirical tests of both adaptive gain and clutter thresholding are needed to investigate several important questions that follow from the above presentation. These questions are:

1. Is the planned spacing of sample points adequate to compensate for spatial variations in rain?
2. Is the one-second delay between the measurement of rain attenuation and clutter and the adjustment of the gain and threshold on the display adequate in view of temporal variations in rain?
3. Are the cells used to apply these enhancements to the display small enough to avoid compromising the display appearance?
4. How readily can grass areas be found that have a consistently low return and that are large enough for clutter sampling?
5. Can clutter sampling areas with low return be created by installing reflective fences?

6. What is the proper size and mounting procedure for the rain gain reflectors?

7. Can permanent 'reflectors of opportunity' be used for the rain gain function?

8. Does the clutter threshold give sufficient additional benefit to merit including it in radar requirements?

Questions 1, 4, 5, and 8 are the ones most important to answer empirically.

In addition to obtaining engineering answers to specific questions about adaptive gain and clutter thresholding it is necessary to obtain an operational level evaluation of the merit of these enhancement functions. Figure 19 illustrates a technique for obtaining such an evaluation at FAATC. What is proposed is that the adaptive gain function only be applied in one wedge-shaped portion for the field, and that 'clutter thresholding' only be applied in another wedge-shaped portion. The remainder of the surveillance area would be displayed normally. This multi-function display could be implemented with very little additional circuitry.

If the radar and enhancement functions were configured as in Figure 18 the relative performnance of each function could be easily observed and recorded on video tape as a storm moved over the field. (The addition of a digital readout of the rainfall rates at the test pads would complete the test display.)

CONCLUSIONS AND RECOMMENDATIONS

The wide dynamic range of the data collected for the ASDE-3 radar allowed off-line simulation of enhanced gain and clutter thresholding functions on the narrow dynamic range display. The results of this off-line processing indicate that the addition of gain to compensate for rain attenuation may restore the 'no rain' appearance, at 1 mile range, for rain rates up to 30-40 mm/hr. The addition of a clutter threshold appears to extend this 'no-rain' restoration to 50-60 mm/hr, and,

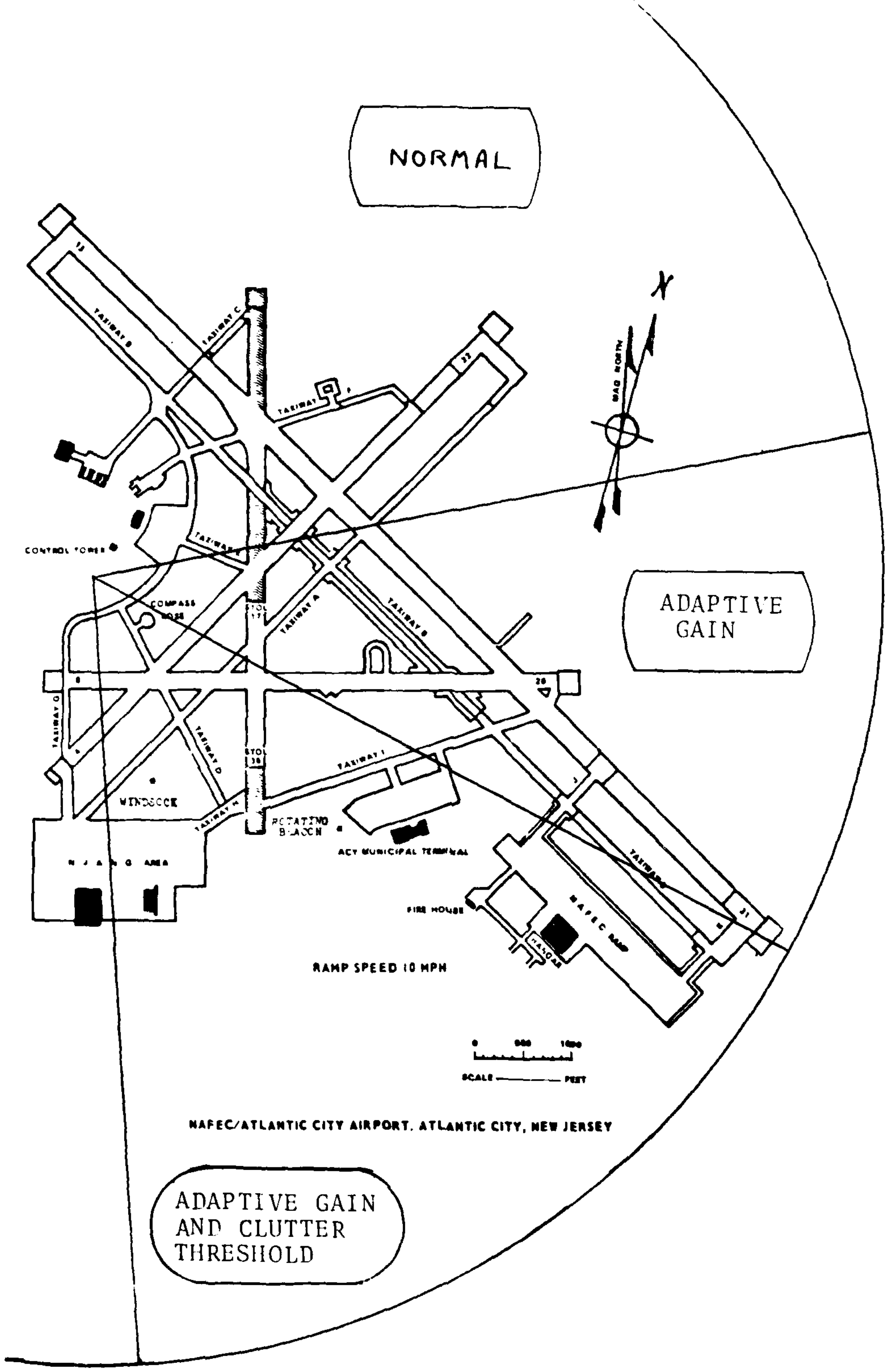


FIGURE 19. POSSIBLE DISPLAY FOR SIMULTANEOUS TEST OF ENHANCEMENT TECHNIQUES FOR TARGET DETECTION IN RAIN

to substantially benefit target detection performance up to 100 mm/hr. These results assume the use of frequency agility which produces a lower peak clutter return, allowing use of a lower threshold for the same false alarm rate so that weaker targets can be detected.

It appears that rain clutter may be effectively measured by sampling the radar returns over an area that normally contains only low level grass returns. When the rain is so heavy that a clutter threshold would be needed, the grass returns will have been attenuated and the predominant return from these areas will be from rain clutter.

Because of non-uniformities in rainfall, samples of attenuation and clutter will have to be taken at many places over the field. The gain and threshold level for each enhancement cell would be set by real-time interpolation from the measured values. Since the processes are similar, much circuitry can be duplicated between the gain and threshold functions.

Because of the limited quantity of ASDE-3 rain data available, several points require further experimental work at FAATC. Notable among these are tests to determine the required quantity and location of sampling areas and to evaluate the relative performance of the unenhanced ASDE-3 radar, the radar plus adaptive gain and the radar plus adaptive gain and clutter threshold, for the same conditions.

APPENDIX B: ALTERNATIVES STUDY FOR EVALUATION OF ADAPTIVE GAIN AND CLUTTER THRESHOLDING

1.0 INTRODUCTION

Studies were made of three approaches to the evaluation of the benefits and practicality of the adaptive gain and clutter threshold enhancements to the ASDE-3 Radar. The first approach was the small scale implementation and testing of these enhancements in new hardware added to the Engineering Model ASDE-3 Radar. The second approach was collection of additional data on ASDE-3 performance in rain, which would allow off-line processing to determine a numerical measure of how well these enhancements could compensate for attenuation and clutter due to rain. The third approach was to use ASDE-3 Engineering Test data consisting of simultaneous measurements of rainfall rates at three points on the airport surface and analyses based on standard attenuation formulas to obtain a result comparable to that of the second approach.

2. EVALUATION OF ADAPTIVE GAIN AND CLUTTER THRESHOLD VIA HARDWARE IMPLEMENTATION

Three system level designs for a limited hardware implementation of adaptive gain and clutter threshold were prepared and evaluated. All designs presumed a limited application region on the airport surface for each enhancement, to minimize the real-time processing loads and simplify design. The circuit and software design efforts were studied for each system design.

2.1. FULL IMPLEMENTATION

The full implementation design would include both the adaptive gain and adaptive clutter threshold functions, with each function to be applicable only over a limited angular region of the airport surface rather than 360° coverage. The radar display would show three types of enhancement regions: normal, adaptive gain only, and adaptive gain with clutter threshold. A possible appearance of this display is shown in Figure 2.1-1.

This design would also provide digital recording of the measurements of attenuation and rain clutter levels from which the enhancement functions are derived. In addition, time and rainfall rate would be sampled and recorded. These recordings would permit off-line processing to determine a quantified measure of enhancement performance, if desired.

The rainfall rate readings and time would be displayed on readouts adjacent to the radar display and continuous videotape recordings would be made of all three during heavy rain, for off-line study and review.

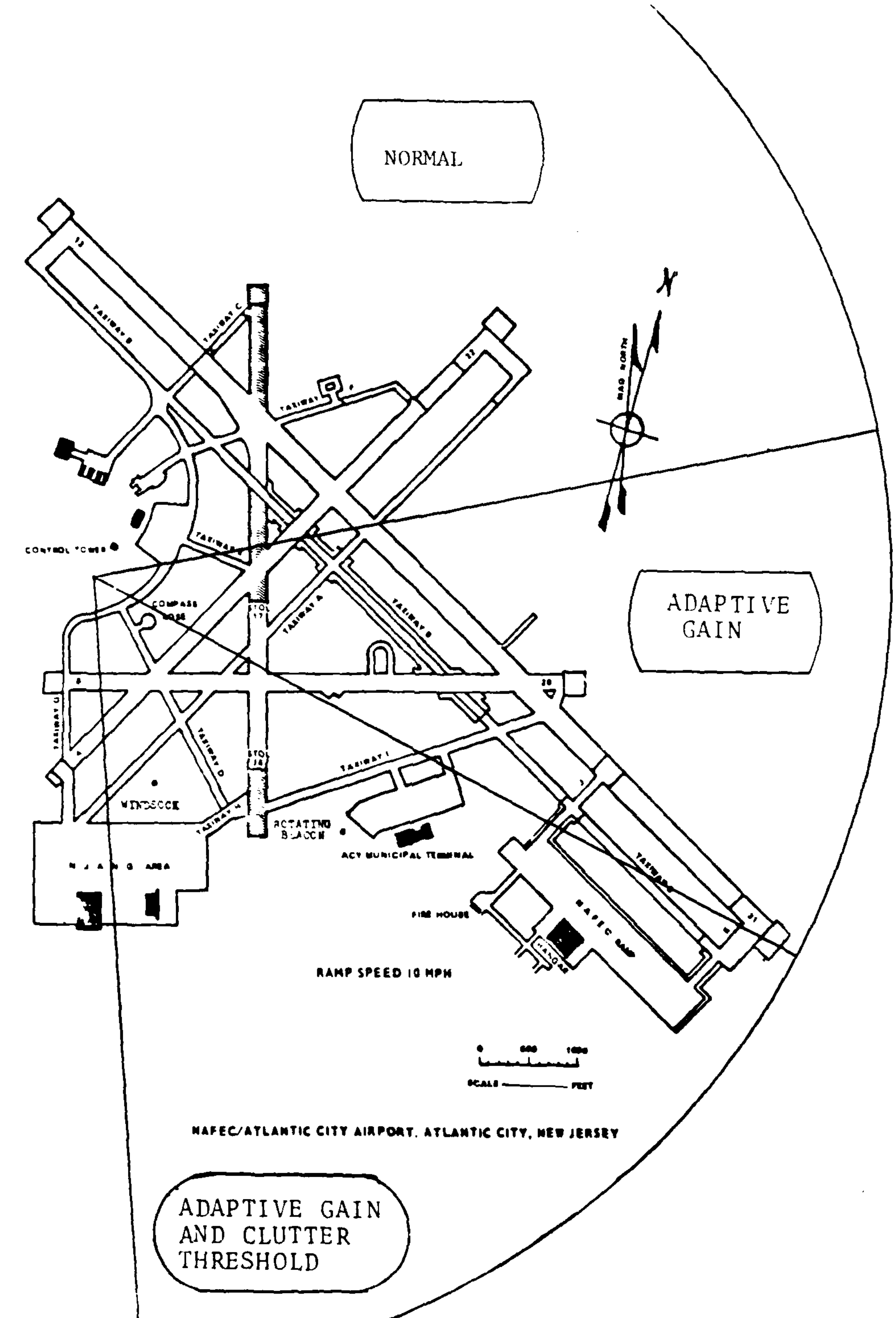


FIGURE 2.1-1. POSSIBLE DISPLAY FOR SIMULTANEOUS TEST OF ENHANCEMENT TECHNIQUES FOR TARGET DETECTION IN RAIN

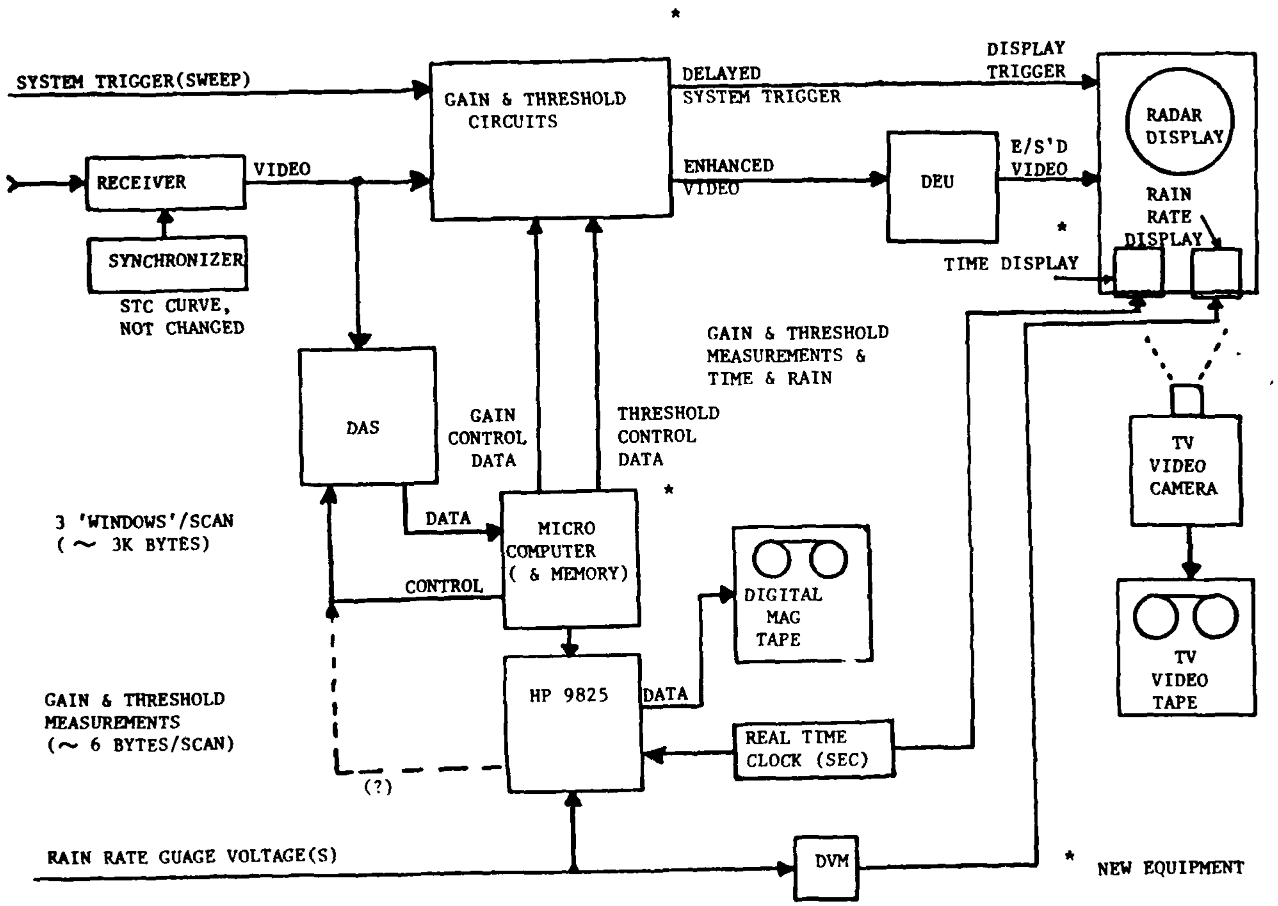


Figure 2.1-2. ADAPTIVE GAIN AND THRESHOLD - FULL IMPLEMENTATION

Figure 2.1-2 shows a block diagram of this 'full implementation' design. New equipment is noted with an asterisk. It was assumed that a microcomputer would be used to: store the locations of the sampling regions and program the ASDE-3 Data Acquisition Subsystem (DAS) to sample each region; calculate and output measures of attenuation and rain clutter from the digitized video samples taken by the DAS; and derive and output appropriate, interpolated, gain and threshold control commands. It was also assumed that gain and threshold circuits (all hardware - no microprocessors) would receive, and perhaps buffer, commands from the microcomputer, and enhance the radar video accordingly. Subsequent study showed that several different approaches to implementing the above functions are possible. These approaches would lighten the software burden on the microcomputer, etc. Table 2.1-1 gives merits and demerits of the "full" implementation for evaluation of adaptive gain and clutter threshold. This design and development effort proved, after detailed examination, to be too large for the available time and resources.

TABLE 2.1-1: ADAPTIVE GAIN & THRESHOLD - FULL IMPLEMENTATION

PRO	CON
1) Will provide a real-time evaluation of both adaptive gain and adaptive threshold (applied one scan after measurement & including azimuth interpolation).	1) There is a major design and development effort required in three areas: a) Gain & Threshold Circuits b) Microcomputer software c) Timing and interfacing)

2.2 ADAPTIVE GAIN ONLY, STC IMPLEMENTATION

The 'STC Implementation' design would not include the adaptive clutter threshold function although a manual threshold would be included for test of the threshold function. The

adaptive gain function would be implemented by adjustment of the existing STC curve in the Engineering Model ASDE-3.

Like the previous design, this design would provide digital recording of the measurements of attenuation and rain clutter levels, as well as time and rainfall rate. Similarly, video tape recordings would be made of the radar display, with time and rainfall rate readouts.

Figure 2.2-1 shows a block diagram of this 'STC Implementation' design. New equipment is noted with an asterisk. As in the 'full implementation' design, it was assumed that a microcomputer would be used to: store the location of the sampling regions and program the ASDE-3 DAS to sample each region; calculate and output measures of attenuation from the digitized video samples taken by the DAS; and derive and output appropriate, interpolated gain control commands. These tasks are reduced from the 'full implementation' in that no rain clutter measurement or interpolation takes place. The gain control data would be formatted as a modified STC curve, and stored in the ASDE-3 synchronizer. In place of gain and threshold circuits used in the 'full implementation' there would be only a synchronizer interface and a manual threshold circuit, shown in Figure 2.2-1.

Table 2.2-1 gives the merits and demerits of the 'STC implementation' hardware design for evaluation of adaptive gain. The design and development effort for the STC approach was judged to still be too large, although reduced from that of the 'full implementation', yet the adaptive clutter threshold would not be evaluated. (It could only be evaluated via off-line data processing, which was the second evaluation approach examined, see Section 2.2). Additionally, the STC approach was considered inferior unless the feedback problem described in Table 2.2-1 could be eliminated by using a separate amplifier as shown in

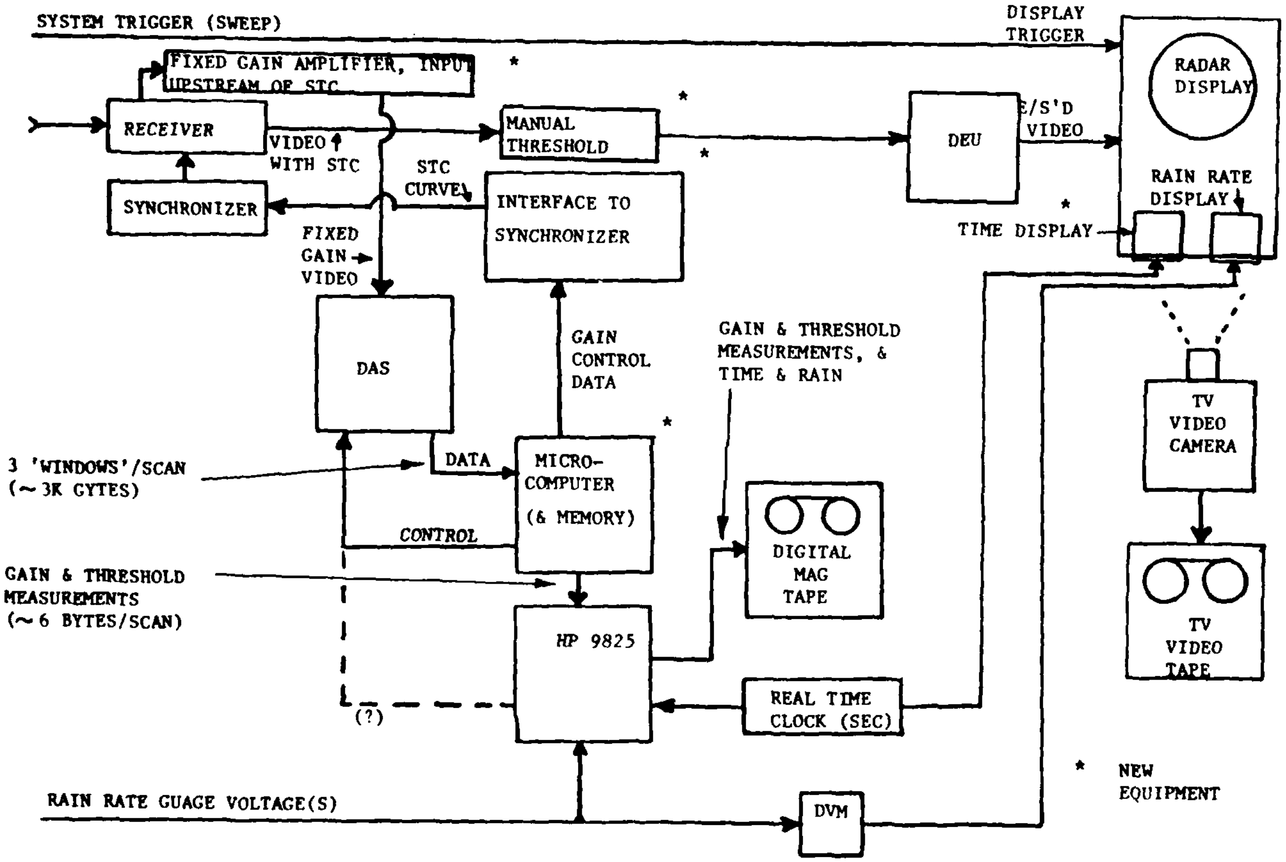


Figure 2.2-1. ADAPTIVE GAIN ONLY, STC IMPLEMENTATION

Figure 2.2-1. Addition of this amplifier would have increased the design complexity back to that of the 'full implementation.'

TABLE 2.2 ADAPTIVE GAIN ONLY, STC IMPLEMENTATION

PRO	CON
1) No additional gain circuitry required, only interface to synchronizer.	1) There is a feedback problem, unless there is a separate fixed-gain amplifier feeding the DAS.
2) Measurements for setting thresholds will be processed & recorded, and the display appearance will be simultaneously videotaped.	2) Adaptive thresholding will not be done in real time and evaluated on the display. (However a 2-level manually switched threshold could be implemented which would allow significant evaluation of the threshold function).
3) Will provide real-time evaluation of adaptive gain, applied 1-scan after measurement, including azimuth interpolation. This will reveal how serious rain clutter becomes as a function of range and rain rate.	3) There is a major design and development effort required in two areas: a) Microcomputer software b) Timing and interfacing

2.3 ANALOG IMPLEMENTATION

The 'analog implementation' design, shown in Figure 2.3-1 would include both the adaptive gain and adaptive clutter threshold functions. This design would provide no digital recording of data and would depend totally on observations and videotapes of the displays for the evaluation. Software would have to be prepared for the existing 9825 computer so that it could preset the Data Acquisition subsystem for each area where the radar returns would need to be sampled. But the 9825 software would be trivial compared to the microcomputer software required by the other designs.

This design would minimize new equipment and software, but the analog sampling and averaging circuits would be complex because samples would have to be taken at the same range on adjacent radar pulse returns, and then averaged, since frequency agility is being used.

Table 2.3-1 gives the merits and demerits of the 'analog only' hardware design for evaluation of adaptive gain and clutter threshold. The design effort for the analog circuitry was considered to be too risky for the available time. More importantly, the fact that this design requires the enhancement to be applied for an entire azimuth sector downstream of a sample (because there would be no memory or interpolation to apply the enhancement on the next scan) was judged to degrade the enhancement capability sufficiently that the evaluation would not be accurate.

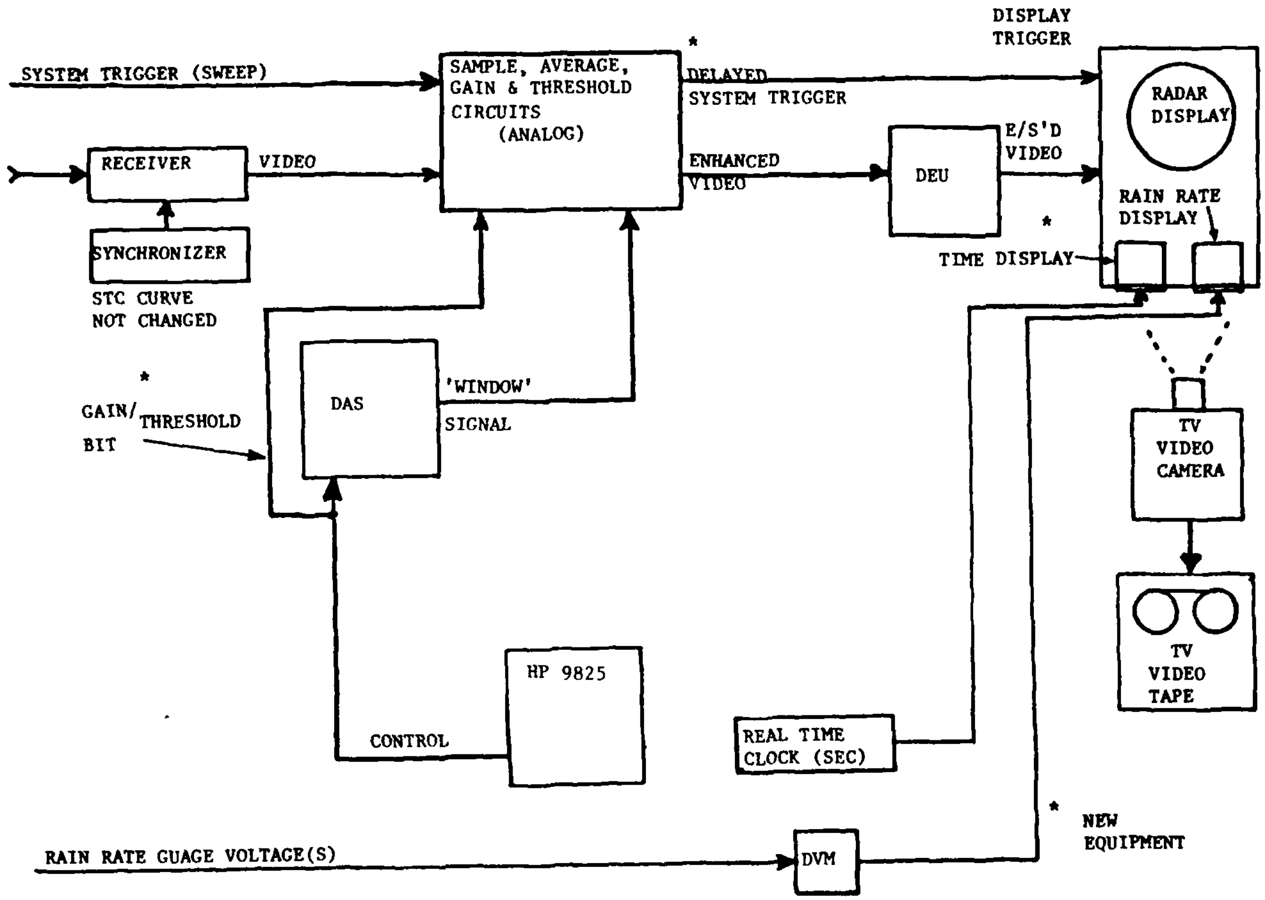


Figure 2.3-1: ANALOG IMPLEMENTATION

TABLE 2.3-1. ANALOG IMPLEMENTATION

PRO	CON
1) No microcomputer required	1) Evaluation of benefit to be made exclusively from video tape of display, no backup data will be taken.
2) No Microcomputer software development required.	2) Significantly more difficult analog circuit design task.
3) No digital tape or interfacing required.	3) Gain & threshold will be applied on same scan as measurement, probably as a step function somewhat delayed in azimuth. No azimuth interpolation will be possible.
4) Will provide a real-time evaluation of both adaptive gain & adaptive threshold subject to point 3 at right.	4) Measurement of target or clutter may not be taken on a single pulse because this introduces too much variance in the measurement. (Several pulses must be averaged).

3. EVALUATION OF ADAPTIVE GAIN AND CLUTTER THRESHOLD VIA ADDITIONAL DATA COLLECTION

Two of the approaches to the design of a hardware implementation for evaluating adaptive gain and clutter threshold (see Section 2.) incorporated recording of digital data. This data was to include all samples used to measure attenuation and rain clutter as well as the time and rainfall rate. It was there proposed to use this data via off-line processing only to check the operation of the enhancement circuits, as recorded on video tapes of the radar display.

Subsequently, it was realized that if measurements of attenuation and rain clutter could be obtained, not only at the points which would be used for determining the gain and threshold enhancements, but also at a point midway between a pair of such points, then a statistical measure of the optimum effectiveness of each enhancement could be calculated. This would be done by calculating the amount of gain and the level of threshold that the enhancement functions would apply at the 'third' point, (by interpolation between the measures at the other two points) and comparing those levels to the actual attenuation and clutter level measured at that 'third' point. When this had been repeated for hundreds of scans, statistics on the effectiveness of each enhancement would have been obtained.

Figure 3-1 shows that the equipment for this data collection is already in place with the exception of a time readout, so start of data collection would primarily depend on completion of re-calibration and other work on the ASDE-3 Engineering Model at FAATC. The TV video recording would enable some visual evaluation of the rain clutter uniformity. If gain could be increased at further ranges this evaluation would be improved,

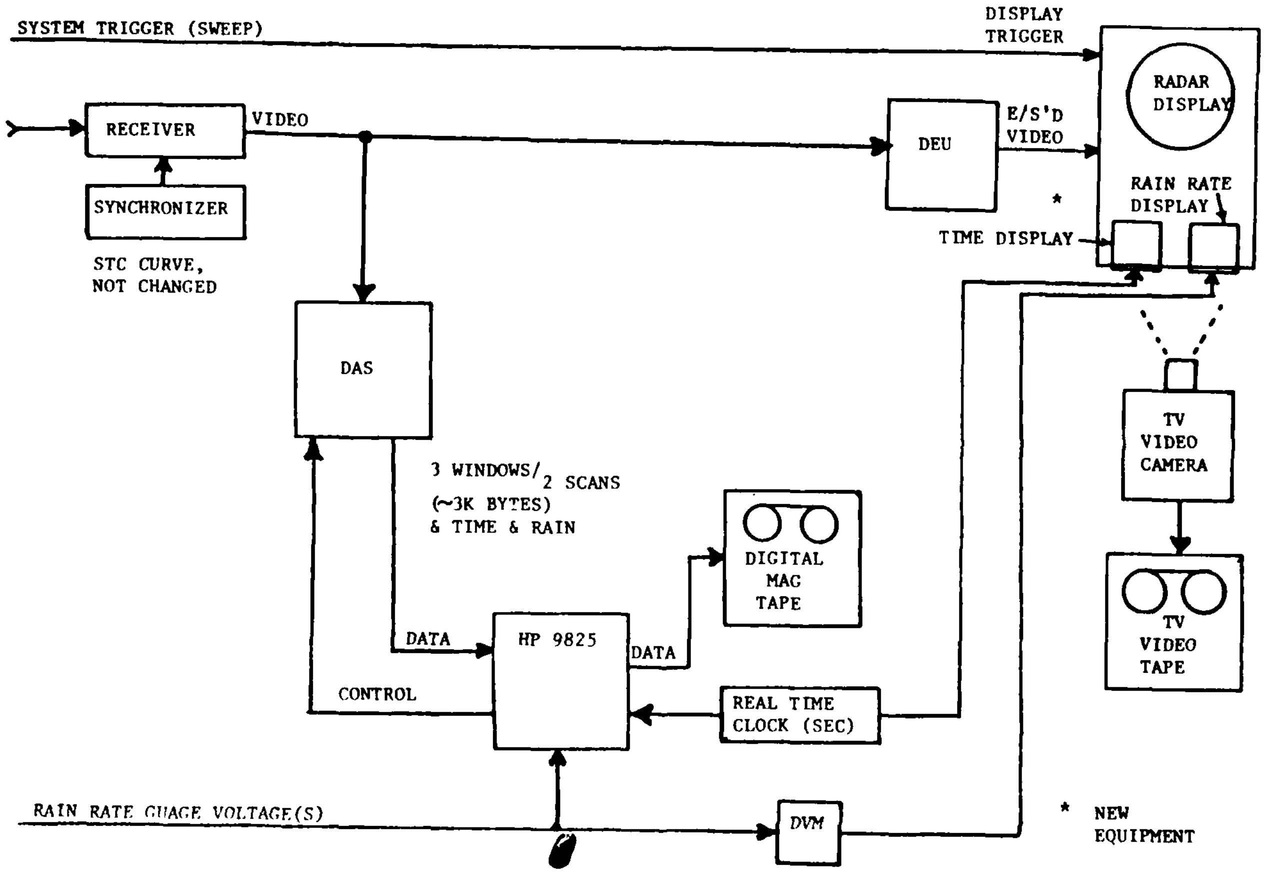


Figure 3-1. LIMITED DATA COLLECTION AND ANALYSIS

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since rain clutter dominates over attenuation only for ranges less than 2,000 feet for this radar.

Table 3-1 gives the merits and demerits of this limited data collection and analysis approach to evaluation of adaptive gain and clutter threshold. Because this approach would yield a numerical measure of the benefit of each enhancement, and because essentially no new equipment and minimal new software would be required it was decided to initiate this approach. The re-calibration of the Engineering Model ASDE-3 Radar was already required in support of other tests such as the evaluation of low loss waveguide.

TABLE 2-1. LIMITED DATA COLLECTION & ANALYSIS

PRO	CON
1. All major hardware is already in place.	1. No real-time evaluation of adaptive gain or thresholding.
2. 9825 software to take 3 windows/2 scans could be created by limited mods to existing software.	2. Measurement of rain uniformity between measurement points would be limited to evaluation of photos from the videotape playback.
3. Start of data collection depends only on completion of calibration work in the field.	3. Although the software for data reduction exists, much man time would be needed to run the data through the programs, select the significant data, locate and photograph the synchronized video frames, and repeat this process until a convincing quantity of reduced data was accumulated.
4. The data would give a measure of the spatial variation of rain attenuation and rain clutter at points that would be used for the adaptive gain and threshold functions. Synchronized frames from the videotape would make it possible to judge the uniformity of rain between the three measurement points.	4. Without a significant increase in gain the radar would never show rain clutter for videotaping beyond 1,500 feet.

Table 3-2 lists the field work at FAATC that was desired before inception of the limited data collection. Items 1 through 5 were prerequisites. The additional items would have greatly improved the information obtained from the test.

TABLE 3-2. FIELD WORK REQUIRED FOR 'LIMITED DATA COLLECTION'

1. Install low loss waveguide, install Rost amplifier, remove pads, etc to maximize available gain.

2. Modify STC curve to maintain gain level currently applied to about 1,500 feet range and to rapidly increase gain beyond that, using gain available from (1).

3. Locate two low reflectivity areas (or create them) at 1,000 feet range and 30° from pad 2, and 7,000 feet range with 50° from pad 2.

4. Install a 0.4m^2 reflector on each area located in (3). (Best to use lobing test and reflectors but could use any reflector that is the correct size and rigid!

5. Calibrate and repair as needed all 3 rain rate gauges.

6. Obtain a legible time readout for the real time clock and position it in front of the radar display.

7. Obtain two more DVM'S, interface them to the other two rain rate gauge lines, and position their readouts in front of the radar display.

8. Obtain 2 new rain rate gauges (tipping bucket?) and remoting for their outputs and position them at the two areas located in (3) (alternative: move gauges from Pads 1 and 3 and use their interfaces and readouts).

9. Install a much brighter 2nd target on Pad 2 and areas located in (3) in addition to the 0.4m^2 targets, to enable measurement of greater attenuation levels.

4. EVALUATION OF THE PRACTICALITY AND BENEFITS OF ADAPTIVE GAIN AND CLUTTER THRESHOLD, VIA ANALYSIS OF RADAR AND RATE OF RAINFALL DATA FROM ENGINEERING TESTS

To support the data collection and reduction effort described in Section 3 and provide verification of the results, an analysis was undertaken of the existing radar data and simultaneous rainfall rate measurements taken during the ASDE-3 Engineering Model Test program. The data was re-examined to determine if it contained more information that could be used to evaluate the performance of the proposed adaptive gain or adaptive clutter threshold functions.

Initially, the temporal variation in the attenuation and target-to-mean-clutter ratio was examined. These measures of temporal variation were used, via crude extrapolation, to give estimates of the spatial variation of these parameters for rainfall rates of interest. Subsequently, the simultaneous measurements of rainfall rate at the three test pads were used, combined with the standard formula for attenuation due to rain, to obtain a measure of the typical error an adaptive gain system could be expected to have at the 'worst case' point. These results, analyzed with optimum assumptions for the behavior of rain clutter were used to obtain an evaluation of the best case improvement/degradation likely to result from an adaptive clutter threshold system.

4.1 OBSERVED TEMPORAL VARIATION IN ATTENUATION AND TARGET-TO-MEAN-CLUTTER RATIO

During the ASDE-3 Engineering Tests the performance of the ASDE-3 Engineering Model Radar in rain was measured by sampling and recording radar returns from a test reflector and a background area every 2 seconds for 40-second intervals. For the present analysis this data was reprocessed to give, for each

40-second measurement interval, the mean and standard deviation of the target-to-mean-clutter-return ratio, the mean rainfall rate at the target location, the mean attenuation of the target, and the mean rainfall rate over the region between the radar and the target. These results are presented in Table 4.1-1 and plotted in Figures 4.1-1, 4.1-2, and 4.1-3.

TABLE 4.1-1. BEHAVIOR OF TARGET VS MEAN CLUTTER RATIO, ATTENUATION, AND RAINFALL RATE FOR 36 FORTY SECOND INTERVALS.

	Mean RR @ Target Location	Target/Mean Clutter Mean	Target/Mean Clutter Two Sigma	Mean RR Between Radar & Target	Attenuation Two Sigma
	mm/hr	dB	dB	mm/hr	dB
Tape 1	4.5	18.9	2.8	12.1	0.8
	9.2	15.9	1.8	32.3	0.6
	9.2	15.9	1.8	22.8	0.6
	17.6	15.1	1.4	42.1	1.4
	18.4	12.4	1.8	38.4	1.6
	6.9	20.5	0.6	6.1	0.6
	11.4	12.0	2.6	26.4	3.0
	19.6	10.5	2.2	17.4	4.5
	0.3	24.4	0.5	0.4	0.6
	0.2	22.2	1.8	0.1	1.6
	0.9	21.5	1.6	2.2	1.2
	0.4	24.9	0.8	0.1	0.8
	1.3	20.7	1.0	7.5	1.2
	1.6	23.3	0.8	1.2	0.8
Tape 2	2.8	20.7	1.4	3.0	1.2
	0.3	20.8	1.0	1.9	1.0
	6.9	18.6	7.2	4.3	2.0
	0.2	24.3	0.4	0.2	0.4
	0.2	23.8	0.6	0.3	0.6
	0.2	23.9	1.0	0.2	0.8
	0.2	24.4	0.8	0.2	0.8
	4.8	14.5	6.2	13.2	1.4
	9.6	12.6	1.8	29.9	2.6
	19.5	11.7	1.4	38.7	1.2
	20.7	9.5	1.4	39.1	1.6
	17.5	12.3	2.6	23.6	2.8
	77.4	1.1	2.4	74.2	3.8
	73.3	3.5	1.9	55.5	4.6
Tape 3	14.5	12.2	3.8	11.2	1.6
	11.2	12.3	1.2	26.8	1.0
	11.3	12.6	1.4	25.4	0.8
	44.6	5.0	3.4	44.5	3.2
	28.5	2.8	2.4	72.3	1.8
	84.2	1.5	2.6	98.4	2.6
	59.0	5.1	2.6	74.0	2.8
	44.6	3.6	1.8	50.0	1.2

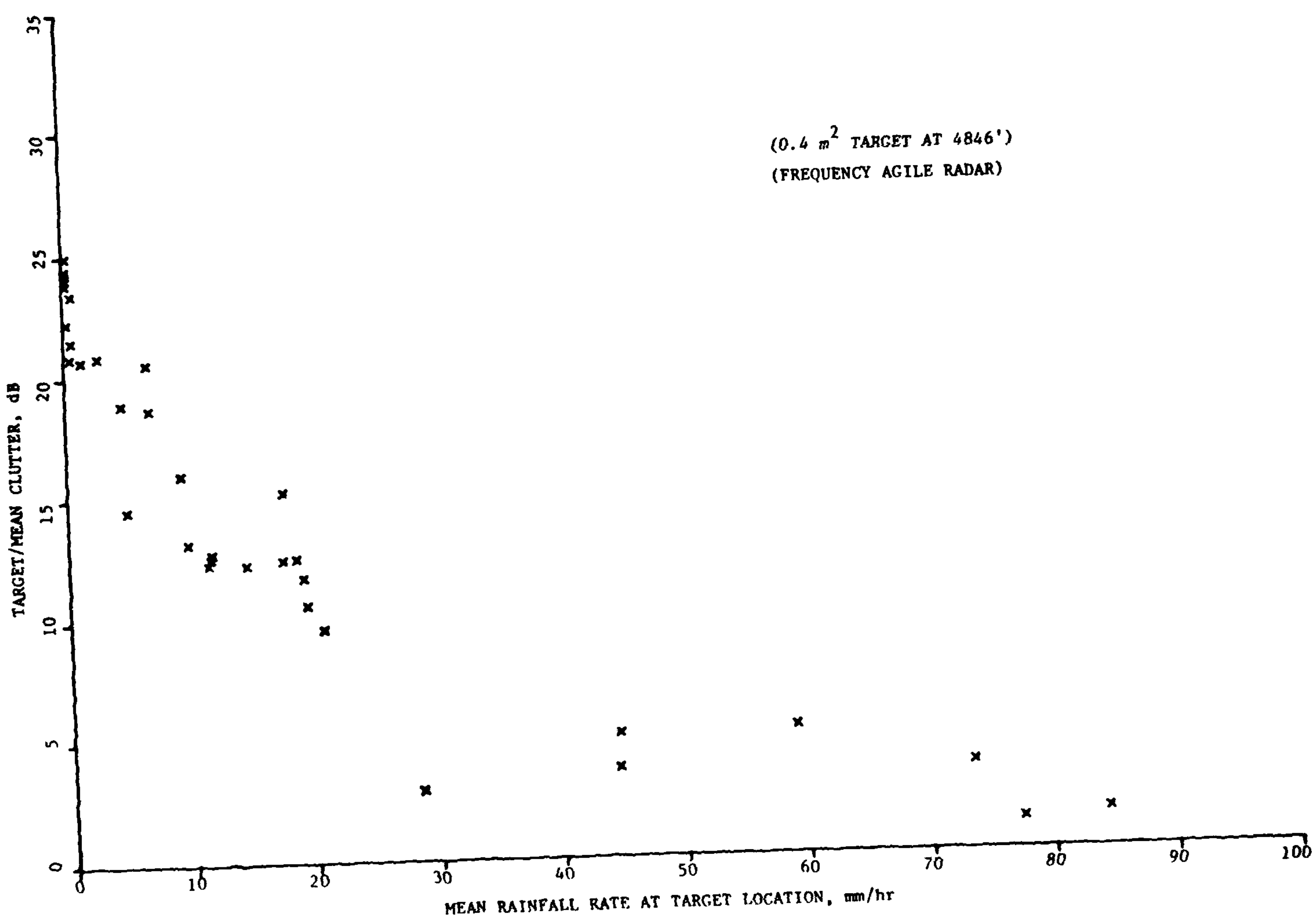

Figure 4.1-1. MEAN OF TARGET/MEAN CLUTTER OVER FORTY SECONDS VS MEAN RAINFALL RATE AT TARGET LOCATION OVER FORTY SECONDS

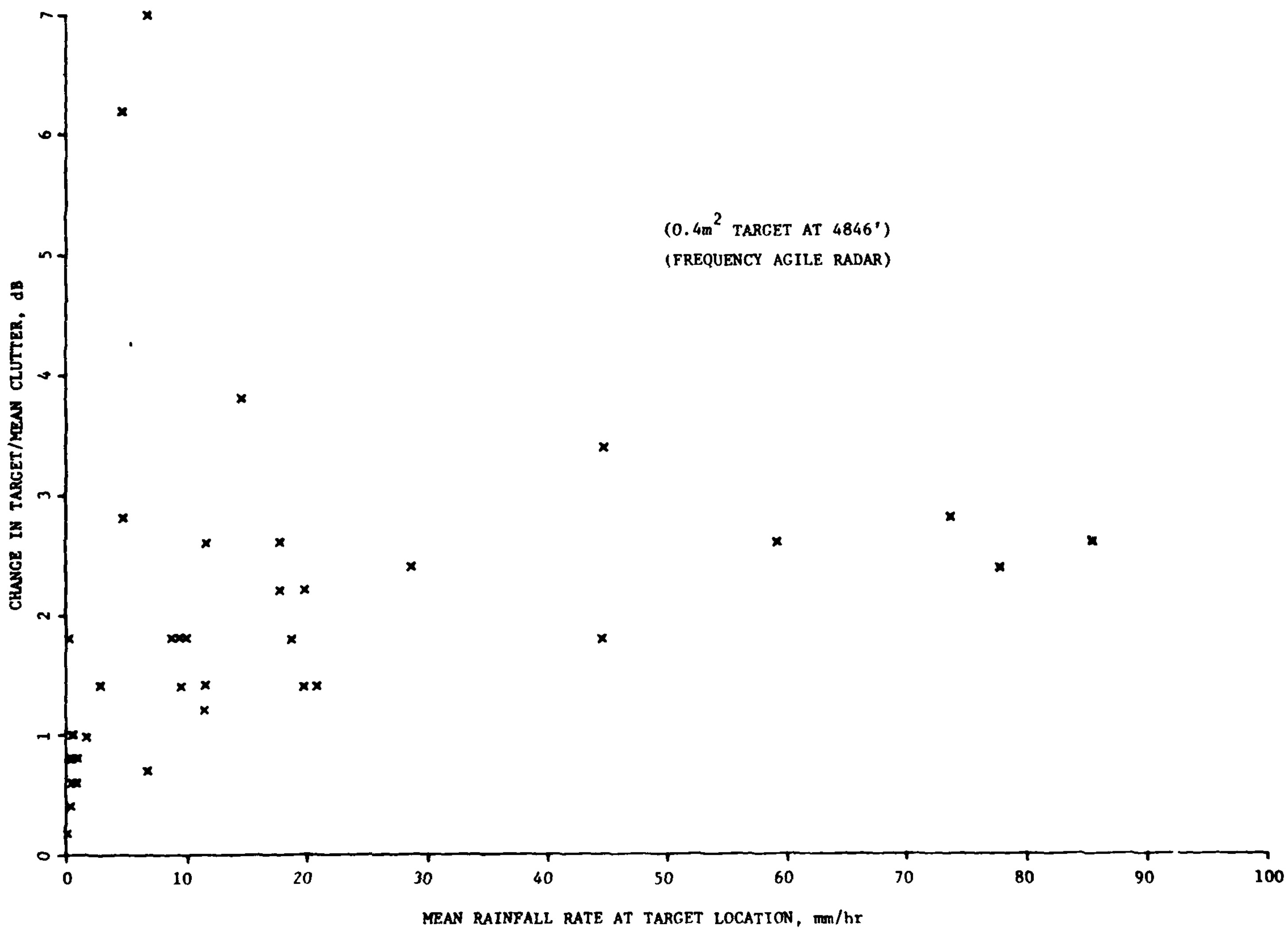

Figure 4.1-2. CHANGE (TWO SIGMA) IN TARGET/MEAN CLUTTER OVER FORTY SECONDS VS MEAN RAINFALL RATE AT TARGET LOCATION OVER FORTY SECONDS

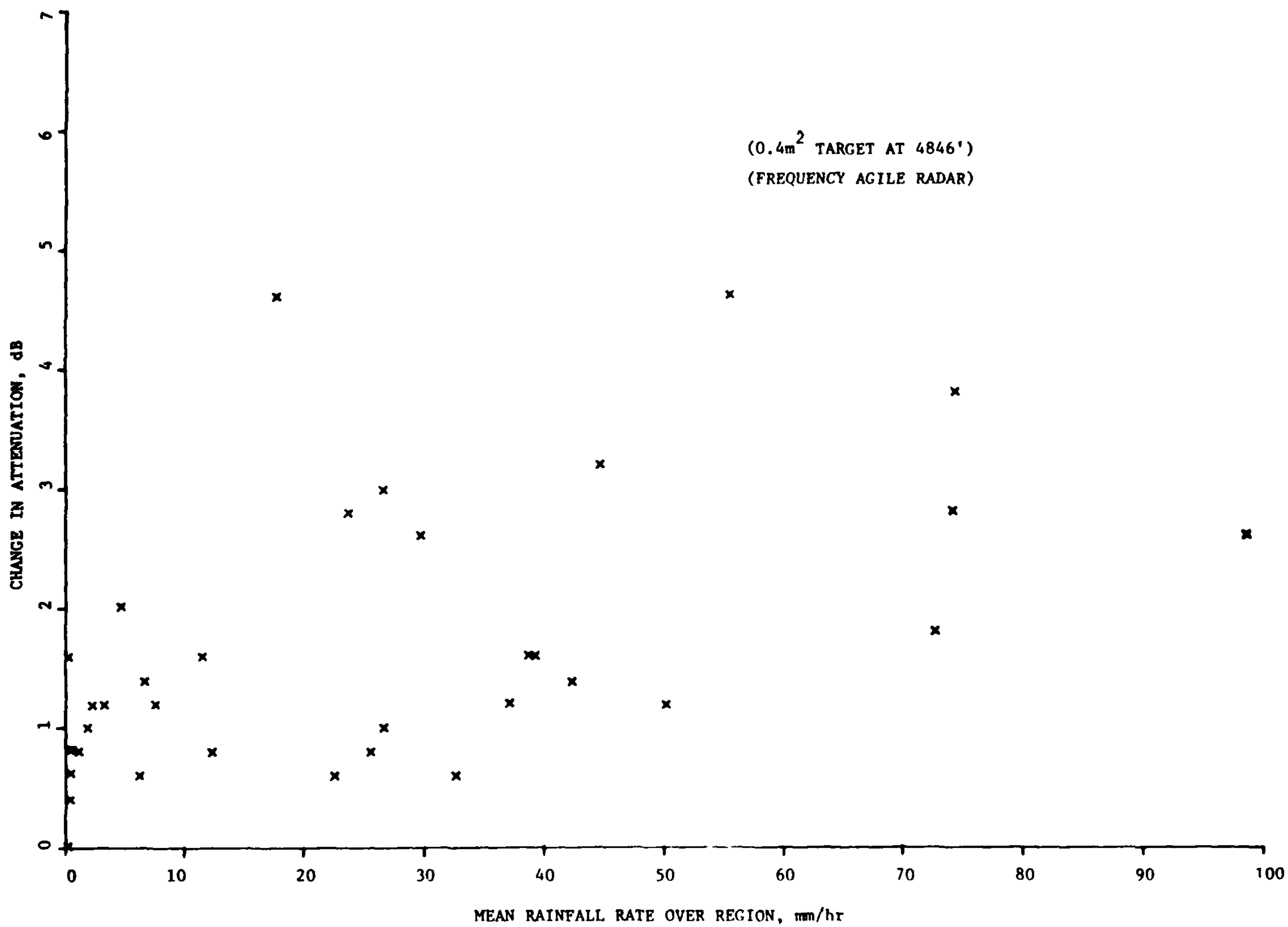

Figure 4.1-3. CHANGE (TWO SIGMA) IN ATTENUATION AT TARGET OVER FORTY SECONDS VS MEAN OF RAINFALL RATE OVER REGION BETWEEN RADAR AND TARGET OVER FORTY SECONDS

This data was then divided according to the average rainfall rate that prevailed during the intervals and further processed to obtain, for rainfall rates of 10 to 100 mm/hr the average 2 sigma variations in attenuation and in target to mean clutter ratio that were observed over 40 second intervals. These results are given in Table 4.1-2. The resulting 2 sigma change in attenuation over 40 seconds is 1.9 dB and the 2T change in target to mean clutter ratio is 2.1 dB.

Although these results refer to the parameters observed at a single point over 40 seconds they do not mean that this is the variation in the storm itself over 40 sec. Rather, since the storm is moving past the point being observed, what we are measuring is a combination of the spatial and temporal variation of the storm.

To obtain a crude extrapolation of this data which will give an estimate of the spatial variation of the storm (over approximately half the distance between two of the reflectors that would be used for adaptive gain, i.e. 4000 feet), we assume: 1) the storm travels at 20 knots (which corresponds to 1350 feet of the storm being observed in 40 sec), 2) the spatial change in the storm from beginning to end of the 1350-foot interval equals the 2 sigma variation of the parameters measured, and 3) the spatial change over three 1350 foot intervals is three times that for one interval or 6 Sigma, (this presumes that the slope of the change in the storm remains constant both in sign and magnitude).

Based on these very conjectural assumptions the spatial variation of the storm over 4050 feet is estimated to be:

5.8 dB change in attenuation

6.6 dB change in mean target to clutter ratio.

These results give a "ballpark" idea of the change to be expected over such distances (i.e. more than 1 dB and less than

12 dB) but they do not show how well this change can be predicted by interpolating between two measurements 8000 to 9000 feet apart.

TABLE 4.1-2. STATISTICS ON CHANGE IN ATTENUATION AND TARGET/MEAN CLUTTER OVER 40 SECONDS

Range of Rainfall Rate (RR)	Mean Rainfall Rate Between Target & Radar	Quantity of 40 Second Intervals	Mean 2T Attenuation over all 40 Second Intervals
RR <1.0mm/hr	0.2mm/hr	7	0.8dB
1.0≤RR<10mm/hr	3.7	7	1.1
10<RR<100mm/hr	39.5	22	2.1

Range of Rainfall Rate (RR)	Mean Rainfall Rate at Target Location	Quantity of 40 Second Intervals	Mean 2T of Target/ Mean Clutter over all 40 sec.Intervals
RR<1.0mm/hr	0.3mm/hr	9	0.96 dB
1.0<RR<10mm/hr	5.7	10	2.5
10<RR<100mm/hr	33.7	17	2.2

4.2. EVALUATION OF ADAPTIVE GAIN AND CLUTTER THRESHOLD PERFORMANCE, BASED ON SIMULTANEOUS MEASUREMENTS OF RAINFALL RATE

As described in Section 2.2, what is needed in order to obtain a statistical measure of the performance of the adaptive gain and clutter threshold enhancements is data on the variation in attenuation and rain clutter levels over the region between two measurement points.

Such data was generated from analysis of simultaneous measurements of rainfall rate that were taken during the ASDE-3 Engineering Tests. Sections 2.1 and 2.2 of the main body of this report describe this process in detail and the results are summarized in section 2.4

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